COMPARISON OF CONSTRUCTIONAL ASPECTS OF DIFFERENT RAILWAY POINT MACHINES

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ABSTRACT

COMPARISON OF CONSTRUCTIONAL ASPECTS OF DIFFERENT RAILWAY POINT MACHINES

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In the last years, railway systems are becoming more popular all over the world, especially in the European Union. Turkey has also started to develop completely domestic products and systems for the railway trains, signaling and infrastructure. Point machines are one of the critical safety devices for the railway signaling and infrastructure. They play an important role in the safe running of rail services. Hence, they have to be quick for the throwing and reliable for the locking of point blades.

This study contains research about modern point machines commercially available in the market and investigations on some of these machines used by Turkish State Railways (TCDD) the major authority running the infrastructure in Turkey. The main objective of this study is to compare different railway point machines in terms of their constructional aspects. This assessment includes three main steps. The first step is to perform research about modern point machines and their operational characteristics. The second step is the detailed investigation of four different point machines that are currently used at the railways operated by TCDD in Turkey. The final step is about comparison of mainly constructional aspects of these investigated point machines for

the purpose of preparing background and guidelines for the development of a novel and domestic point machine.

Keywords: Point machines, railway, electro-mechanical, electro-hydraulic, electro-pneumatic.

ÖZ

FARKLI DEMİRYOLU MAKAS MOTORLARININ YAPISAL YÖNDEN KARŞILAŞTIRILMASI

Ovalı, Orçun
Yüksek Lisans, Makina Mühendisliği Bölümü
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Raylı sistemler son yıllarda Avrupa Birliği başta olmak üzere bütün dünyada gittikçe popüler olmaktadır. Türkiye de raylı taşımacılık alanında ulusal tasarım ve üretim demiryolu araçları, sinyalizasyonu ve altyapıları için ürün ve sistemler geliştirmeye başlamıştır. Makas motorları, demiryolu sinyalizasyonu ve altyapı sistemleri için güvenlik açısından kritik cihazlardan biridir. Bu cihazlar raylı ulaşım sistemlerinin güvenli olarak sürdürülmesi konusunda önemli rol oynamaktadır. Bu nedenle makasların konumlandırılması sırasında hızlı, kilitlenmesi açısından da güvenilir olmaları gerekmektedir.

Bu çalışma, piyasada mevcut, çağdaş makas motorlarının araştırılmasını ve Türkiye Cumhuriyeti Devlet Demiryolları (TCDD) tarafından kullanılan dört farklı makas motorunun incelenmesini kapsamaktadır. Çalışmanın esas amacı farklı makas motorlarının yapısal özelliklerinin karşılaştırılmasıdır. Çalışma temelde üç ana adımdan oluşmaktadır. Birinci adım, çağdaş makas motorlarının ve işlevsel özelliklerinin araştırılmasıdır. İkinci adım, TCDD tarafından hali hazırda Türkiye'deki demiryollarında kullanımı devam eden dört farklı makas motorunun incelenmesidir.

Son adım ise özgün ve yerli bir makas motoru geliştirilebilmesi için gerekli altyapı ve prensiplerin ortaya çıkarılması için, makas motorlarının yapısal özelliklerinin karşılaştırılmasıdır.

Anahtar kelimeler: Makas motorları, demiryolu, elektro-mekanik, elektro-hidrolik, elektro-pnömatik

To My Loved Parents and My Handsome Brother…

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LIST OF SYMBOLS

λ	: Degree of freedom of the space
l	: Number of links
j	: Total number of kinematic joints
F	: Degree of freedom
i	: Joint number
f_i	: Degree of freedom of i^{th} joint
L	: Number of independent loops
V	: Velocity
a	: Acceleration
t	: Time

LIST OF ABBREVIATIONS

AC	: Alternating current
CTC	: Centralized traffic control
DC	: Direct current
DIN	: German institute for standardization (Deutsches institute für normung)
EN	: European standard
ETCS	: European train control system
GSM-R	: Global system for mobile communication - railway
IEC	: International electro-technical commission
IP	: Ingress protection
LRV	: Light rail vehicle
MTBF	: Mean time between failures
MTTR	: Mean time to repair
PLC	: Programmable logic controller
SIL	: Safety integrity level
TCDD	: Turkish State Railways (Türkiye Cumhuriyeti Devlet Demiryolları)

NOMENCLATURE

Stock rails	: the fixed running rails along a railroad track, see (1) in Appendix A.
Point blades	: the movable rails guiding the train wheels towards either the straight or the diverging track, see (2) in Appendix A.
Throwing stroke	: the distance that the point blades are moved between the stock rails to change the position of a point, see (3) in Appendix A.
Throwing time	: the time elapsed during the operation of a point machine to change the position of a point. It includes unlocking, throwing motion, locking and detection.
Throwing force	: the force that the point machine can apply for the throwing of point blades.
Driving rod/bar	: the rod or bar inside the point machine used for the throwing of point blades. It is connected to the point blades with a mechanical linkage, see (4) in Appendix A.
Detector rod/bar	: the rod or bar inside the point machine used for the detection of locked end positions of the point blades. It is connected to tip of the point blades with a mechanical linkage, see (5) in Appendix A.
Eurobalise	: an electronic transponder placed between the rails of a track which transmits messages to the balise transmission module of the on-board ERTMS.

CHAPTER 1

INTRODUCTION

Point machines are used to operate the railway turnouts and considered as crucial devices in the railway industry since the failure of these machines results in delays, rise of operating costs and, most importantly, train accidents. Therefore they are becoming more important for the safe and efficient running of trains, especially with the use of high speed trains in the last decades.

Turkey has also become aware of the importance of rail transportation and has been started to research and develop domestic products and systems for the railway business. Developing completely domestic point machines, which are considered as the key component of the railway signaling and infrastructure, is an important target in the near future.

The aim of this study is comparison of constructional aspects of different railway point machines to prepare background and to acquire guidelines for the development of a novel and domestic point machine. This study includes the investigations of four different point machines which are used by TCDD. In the first part, modern point machines commercially available in the market and their specifications are researched to get the information about their operational and constructional characteristics. In the second part, four different point machines, which are used by TCDD at the railways in Turkey, are investigated in terms of constructional aspects. In the final part, constructional and operational aspects of these point machines are compared to bring out their advantages and disadvantages relative to each other.

In the first step, the history of point machines are reviewed to learn the historical development and principal functions of them. After that research on different types of modern point machines available in the market is conducted but the number of point machines included in this study is limited to twelve.

In the second step, detailed investigations of four different point machines borrowed from TCDD are performed. The brand names or models of point machines are not given in this study in order to avoid making advertisement or smearing the brand names. For this reason they are entitled by the letters like point machine A, point machine B and so on. These machines are examined in terms of mainly constructional aspects such as casing materials, power packs, electric motors, power transmissions, driving mechanisms, throwing times, strokes and forces, locking mechanisms, electrical contacts and manual operations within the scope of this study. Position and force analyzes are performed by custom developed Matlab codes.

As a final step, constructional aspects of researched and investigated point machines are compared. In addition to investigations, the experience of TCDD staff, who are working more than 20 years on the maintenance and signalization services, are also valuable for the comparison of the machines. Based on the investigations and experience of TCDD staff, advantages and disadvantages of the machines are presented.

At the end, in accordance with the aim of this study, the background obtained from the research and investigations is summarized and guidelines for the development of a novel and domestic point machine are introduced.

CHAPTER 2

LITERATURE REVIEW

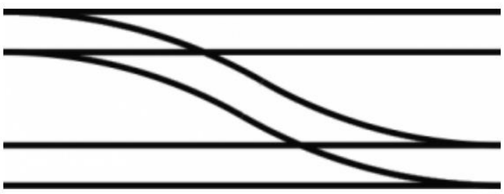
2.1 POINT MACHINES

Railway points or switches are the fundamental parts of the railway infrastructure in such a way that they allow rail vehicles to be guided from one track to another. Railway points are simply the movable rails which give a lead the wheels towards either the straight or the diverging track (Figure 1).

Figure 1 Photograph of a railway point (switch) at Arifiye train station in Turkey, 12.09.2017.

These railway points are placed at the track turnouts that enable one track to cross another track and there are several types of turnouts such that simple turnout, single crossover, double crossover, double slip switch (English connection), equilateral (WYe) turnout and three-way turnout (Figure 2).

(a)



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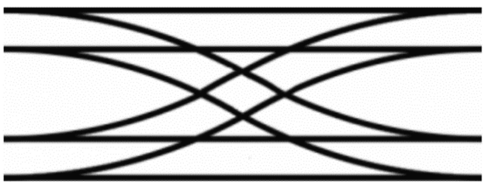

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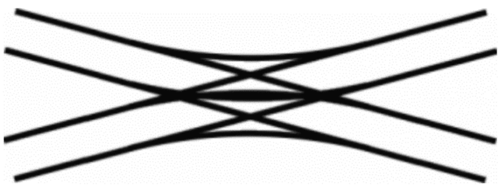


(d)

(e)

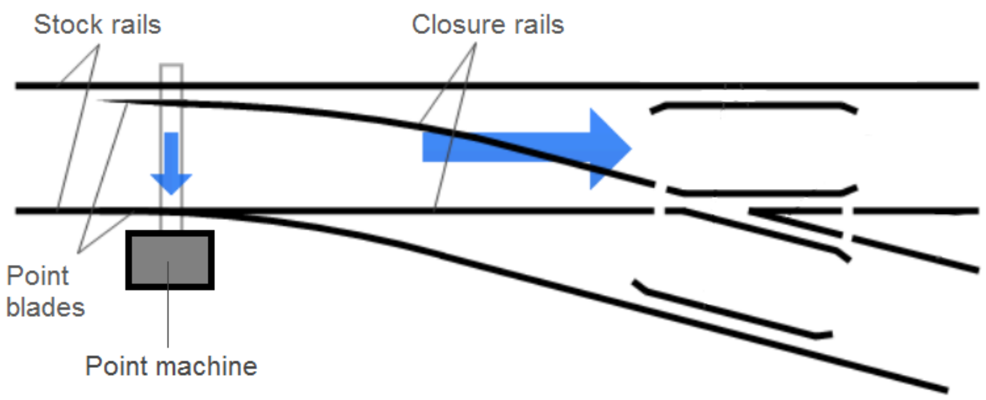
(f)

Figure 2 Schematic representation of simple turnout (a), single crossover (b), double crossover (c), double slip switch (d), equilateral turnout (e) and three-way turnout (f) [1]

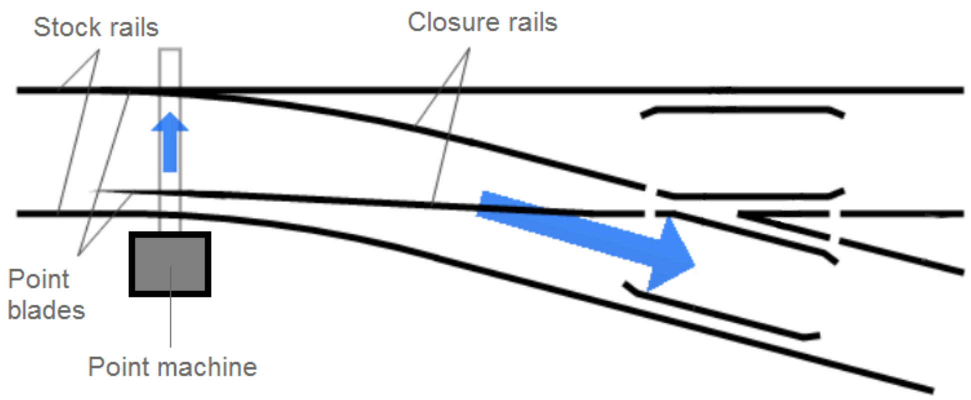
Regardless of the type of turnout, a point operating device namely *point machine*, also known as *point motor*, *switch machine* or *switch motor*; moves the point rails from one orientation to another by

- manual (hand) operation
  - in-situ
  - remote
- electro-mechanical
- electro-hydraulic
- and rarely electro-pneumatic actuated mechanisms.

As shown in Figure 3, a point machine basically aligns the points with one of the possible routes and secures them at that position. They are positioned at the beginning of the turnouts.



(a)



(b)

Figure 3 Schematic representation of a point allowing the train to straight track (a) and to diverging track (b) (adopted from [1])

The point machine principally performs the following three main functions:

1. Moving the point blades
2. Locking the point blades at the desired position
3. Detecting and proving the position of the point blades.

2.2 HISTORY OF POINT MACHINES

In the earliest times, railway points at the turnouts were operated to guide the trains by means of a simple lever manually and locally. They are known as *point lever*, *ground throw* or *switch stand* in the literature, and usually mounted on a pair of long sleeper which extend from the underneath of point rails as shown in Figure 4. The two point rails are connected together with a rigid throw bar and the throw bar extends to the point lever on the side of the track. They have also usually some sort of targets like reflector or lamp on them allowing the switchman or approaching train to see the position of the point rails.

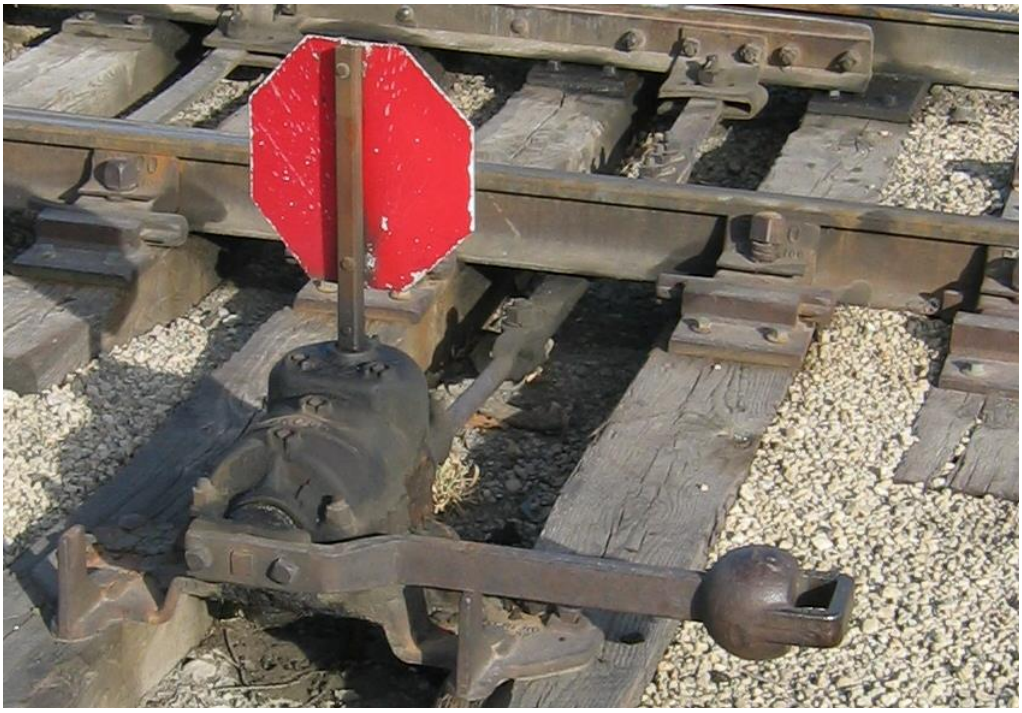


Figure 4 Photograph of an old switch stand with a reflector target on top [2]

There are different designs of manual point levers as shown in Figure 5. Main aim is to move the points into intended position and to prove this position of the rails.

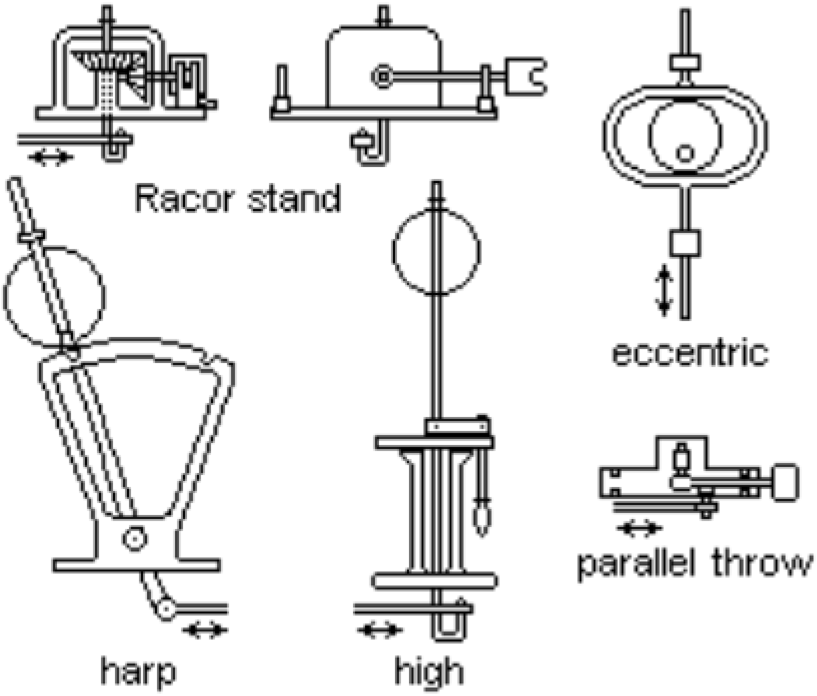


Figure 5 Schematic views of different switch stand designs [3]

Switch stands usually convert a rotary motion about a horizontal or vertical axis to a linear motion by means of an operating rod. The earliest and simplest type is the harp switch stand and it has a pin on the lever to hold it in the desired position. Parallel throw type switch stand operates through 180^{o} angle and it is held on the desired position by the weight of the handle although it may also be latched in that position. The high switch stand operates through 90^{o} angle about a vertical axis and the operating handle folds down into a notch to lock the mechanism at the adjusted position. The height of this type of switch stands varies according to design requirements. Low profile switch stands are used at locations where there is not sufficient clearance for tall switch stands. It also depends on the distance of the switch stand from the track. High profile switch stands are used freely if they are sufficiently far away from the track (Figure 6) [3].

Figure 6 Some examples of different switch stands with different heights [4]

The eccentric switch stands were used on the London and Birmingham Railways in 1830's. In the next years, they were exported to early railways in Europe, extensively to France. They give a definite stroke equivalent to twice of the eccentricity. The eccentric is rotated through 180° about vertical axis by the help of a handle. Racor type switch stands are the most commonly used low profile switch stand. The handle is rotated through 180° about horizontal axis parallel to the track. Thus the vertical axis rotates through 90° driven by bevel gears. The operating lever is held by latching on each side and a foot pedal is used to release these latches. As an additional protection to prevent tampering with the switch, the latches can also be padlocked as shown in Figure 7.

Figure 7 An example of racor type point lever and padlocked latch in a position [5]

Prior to widespread availability of electricity, a decentralized network of control points which are known as signal boxes are constructed near the tracks to control the turnouts remotely, at distances up to about 300 meters.

Figure 8 Bardon Hill signal box in Leicestershire, England is a Midland Railway signal box dating from 1899. [6]

Points were operated by the system of rod and levers as shown in Figure 9. These levers were also used to control railway signals to keep the train movements over the points under control. Signaling control provides an interface between the human signal operator and the trackside signaling equipment. The signal box provides a dry, climate controlled place for the elaborate systems and also dispatchers. Most signal boxes were designed as raised from the track level and this allows the dispatcher to have a good view of the railway. The first signal box was used by the London and Croydon Railway in 1843 to control the junction to Bricklayer’s Arms in London as seen in Figure 8 [7].

(a)

(b)

Figure 9 Photograph of a mechanical lever frame inside the signal box (a) [8] and point arrangement box with wire rope (b) at Sabuncupınar in Turkey, 18.11.2006. [9]

As time goes, number of turnouts increased with the number of tracks and design of track layouts restricted the mechanical operation of turnouts. This also requires more signal boxes to control the increased number of turnouts. On the other hand, railway administrations have always a desire to increase the distance that the turnouts can be operated remotely. This brings the need of some kind of power operation for point machines. The required means of power operation include electro-mechanic, electro-hydraulic and electro-pneumatic.

With the practical development of the electric power, eventually purely mechanical systems were combined with the developing electrical power control systems. In the transition period to modern point machines, electric power was firstly used to operate these machines. Thus first examples of the modern point machines have begun to come out.

At a later time, electro-pneumatic and electro-hydraulic powered mechanisms were developed to set the points at the desired position.

Electro-pneumatic powered point machines are not preferred in the modern times, although they are fast, powerful and have capability of moving the points in snow and ice. The main source of power is fed from an air reservoir with pipes and valves. One of the disadvantages of the pneumatic powered point machines is that they are not as compact compared to other type of point machines. Secondly, compressors and other pneumatic equipment have relatively higher initial costs and require more maintenance. In addition to all of these, the time spent for maintaining the compressor and other pneumatic equipment is also another problem (Figure 10).

Figure 10 An electro-pneumatic point machine fitted to 225A points, north of Bletchey Station in England, 27.09.2012. [10]

Nowadays, the electro-mechanical and electro-hydraulic powered point machines are being used frequently. They have mechanical transmission or hydraulic power packs driven by electric motors as an operational power to move the mechanics. All types of modern point machines also include electrical contacts to detect complete switching and locking. If these switches fail to do any one of these functions, which means that switching of the points are not completed or points are not locked at the desired position, a governing signal is kept as color red. In the case of emergency or power failure, recent point machines may be operated by some kind of manual handle to achieve their function.

Considering the leading technology, basic structure of a modern point machine can be summarized in Figure 11.

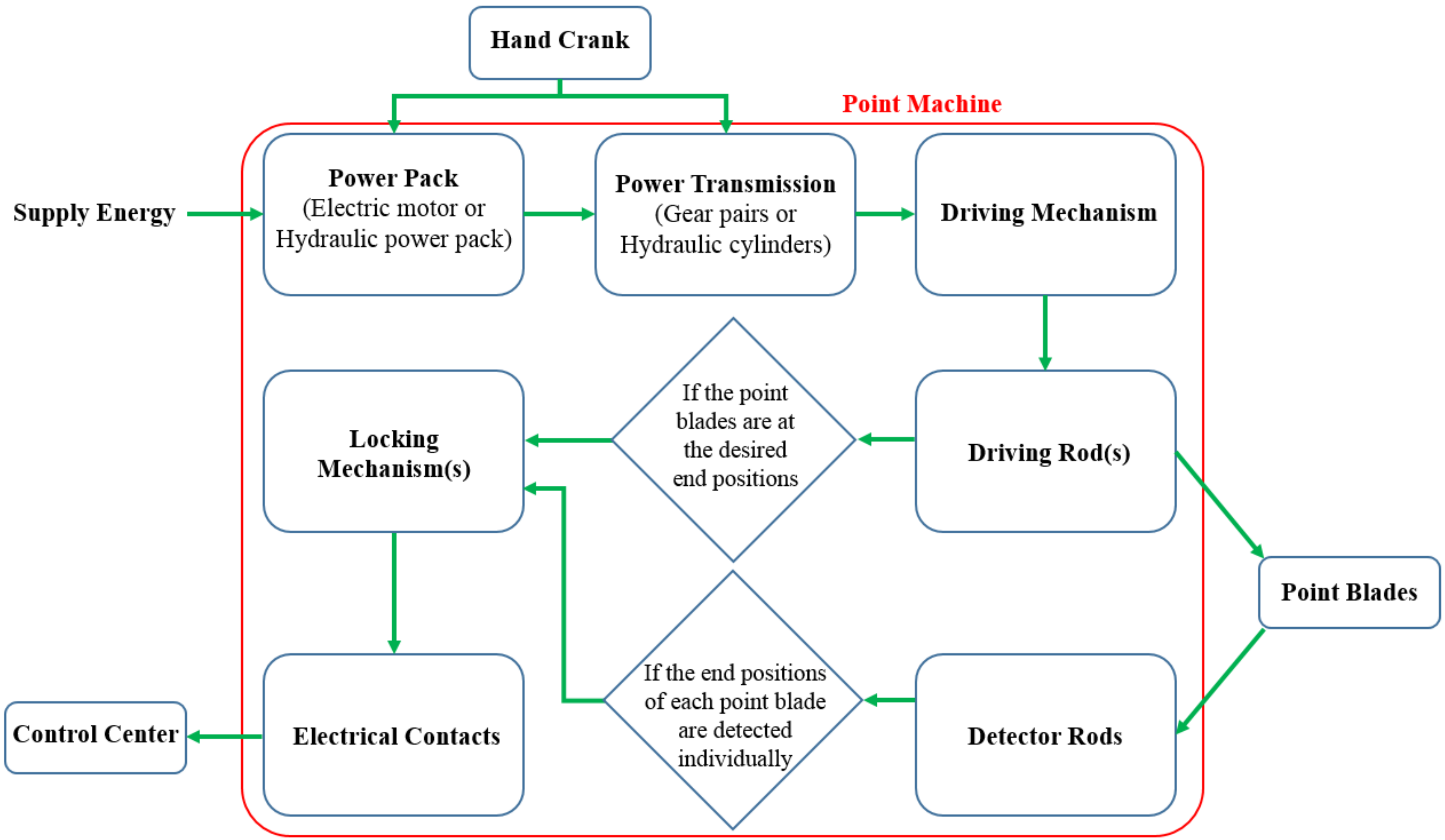


Figure 11 Fundamental structure of a modern point machine

With the increasing traffic on the rail lines, signaling systems are developed to operate and control the railway traffic in a safe, efficient and economic manner. These signaling systems have been improved with the developing technology such that they completely control the rail vehicles. There are several kinds of signaling systems operated in different countries all over the world. Centralized Traffic Control (CTC) is one of the railway signaling systems and it is used by TCDD in Turkey. It is a rail traffic control system that the running of rail vehicles are managed with the electrical signals from a centralized office. Railway signals generated by CTC can be illustrated as block signals, maneuver signals, entering and exiting signals. Point machines are one of the important devices of railway signaling and operated through CTC by the central command from the control center. Operation commands for the point machines are first transmitted with low current values to run the relays in the relay panels which are constructed near the point machines. Then the relays allow operating the point machines. Operation energy passes through the relays is supplied from 3 different sources: main power grid, catenary and battery. Battery is used in the absence of main power grid and catenary.

Over the years, lots of different train control and protection systems have been developed depending on national requirements, operating rules and different standards. However development of independent signaling systems leads to difficulties for the cross-border operations, especially in the European network. Therefore European Train Control System (ETCS) is promoted by the European Commission in 1989 to establish common rules for the free movement of the rail vehicles in all countries. Development of international rail traffic, increased competitiveness, better inter-working of rail services, reduced costs and improving the quality of rail transport are aimed by unifying the multiple signaling systems. ETCS supplies all necessary information like speed limits, instantaneous position and oncoming turnouts to the driver through the cab display for the safe driving by using the equipment such as eurobalise antenna and GSM-R radio modules installed on board and track side. ETCS, in fact, works as an automatic train control system. For example, if the train speed exceeds the maximum limit allowed despite the informative signals supplied by the system, emergency brake is activated automatically [11].

Although the development of signaling systems from CTC to ETCS brings many advantages in terms of railway traffic control and train protection, the method of operation of point machines is not changed much. Programmable logic controllers (PLC) and micro-controllers have been started to use in addition to relays for processing of operation commands. Then the point machines are energized as the part of interlocking to drive the point machines.

In a recent development, some point machines have been started to be operated by wireless communication at short distances. This is considered as a useful method especially at the railway points of relatively slow vehicles like trams. In this manner, driver of the tram can operate the point machine by wireless communication.

2.3 MARKET RESEARCH

In the railway transportation market, there are a number of different types and brands of point machines all over the world. These point machines may be classified in different categories. Some example categorizations are as follows:

According to usage area:

- Light rail vehicle (LRV) rails
- Standard rails
- Mass transit rails
- High speed rails

According to type of power:

- Electro-mechanical
- Electro-hydraulic
- Electro-pneumatic (rare)

According to direction of traffic:

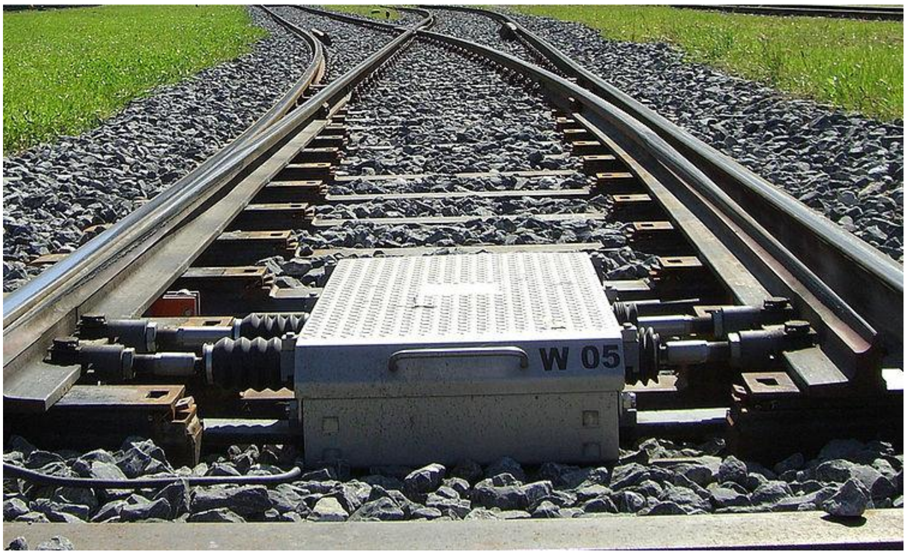
- Trailable: the machines allow the railway vehicles to pass through the points in a trailing direction even if they are not actually arranged for that route.
- Non-trailable: the machines do not allow the railway vehicles attempting to pass through the trailing points that are set incorrectly. In the case of this passing is attempted, it results in damage to the point machine and the train could also be derailed.

According to installation position (Figure 12):

- Right
- Left
- Central

(a)

(b)



(c)

Figure 12 Installation positions of the point machines: right (a), left (b) and central (c) [12]

These categorizations can be increased but the main idea is basically to move the rail points, lock them at the desired position and prove that position of the point blades with the help of some kind of detection.

In this section, some of the contemporary point machines commercially available in the market and their specifications were examined.

2.3.1 SIEMENS POINT MACHINES

Siemens Mobility Division has rail solutions including automation and signaling products. Point machines are also designed and produced by Siemens as part of the signaling products. Some of the products and their specifications are given below.

2.3.1.1 S 700 K POINT MACHINE

Siemens' this type of point machine illustrated in Figure 13 was designed for points with external locking and it is suitable for use in mass transit, mainline transport and also high speed lines with points of all types and gauges.

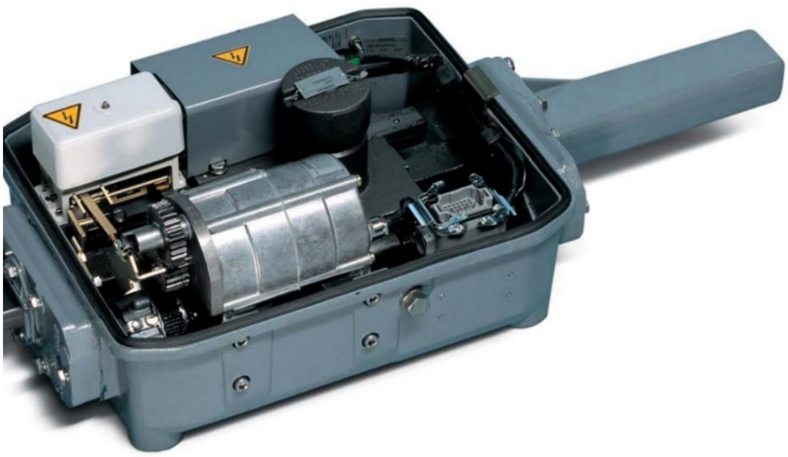


Figure 13 Siemens S 700 K type of point machine [13]

As indicated in the product catalogue, this machine can be used economically both in short- and long-distance rail traffic by rail operators all around the world. Life-cycle costs of the product are kept low thanks to long maintenance intervals and short out of service periods [13].

According to Siemens the mean time between failures (MTBF) of the machine is around 550000 hours.

This point machine has various versions, and customer-specific options are the following:

- Trailable or non-trailable
- Right or left-hand mounting
- With or without point detectors
- Various motor types
- Variable throwing stroke
- Variable throwing force
- Variable throwing time

As it is mentioned by Siemens, all components of the machine are placed in a cast-iron housing and hot galvanized sheet-steel cover with a key locked. The parts that need to be checked are located such that they are easily accessible for the inspection and maintenance activities. This point machine provides the degree of protection IP54 compatible with EN 60529 (see Appendix D).

Siemens explains the working principle of the machine as follows. The ball spindle drive takes the power from the motor through the agency of transmission gearing and converts the rotary movement of the motor into a longitudinal motion. An adjustable transmission clutch limits the throwing force of the machine. A notched clutch is designed as an optional trailing clutch enabling the points to be trailed. The throwing bar is connected to the point blades and held with a defined force by the trailing clutch in the end positions. The trailing clutch is set free when the retention force is exceeded during the trailing of the trailable point machine.

The point machine has also detector slides for fail-safe detection of the blade end positions. They are connected to the point blades through the detector rods and detect the end position of the point blades continuously. The motor is switched off by control contacts once the end position has been detected.

Siemens claims that, more than 30 000 point machines of type S 700 K are in use worldwide.

Table 1 shows the technical data of S 700 K type of point machine.

Table 1 Technical data of Siemens S 700 K point machine [13]

Motor	400 V AC, 50/60 Hz, 3~; 110 V DC to 136 V DC (others on request)
Throwing force	5500 N
Retention force	7000 N
Max. permitting restoring force of point blades	1400 N
Trailing resistance	9000 + 500 N
Throwing stroke	150 mm, 220 mm (others on request)
Throwing time	For 150 mm stroke, 5 s For 220 mm stroke, 6 s
Rated current	2 A*
Starting current	8 A*
Weight	Approximately 120 kg
Degree of protection	IP54 as per EN 60529

Temperature range	-30ºC to +70ºC
*for 400 V, 3~ AC / 50 Hz and a core resistance of 45 Ω	

Some important dimensions of S 700 K are presented in Figure 15 as in mm.

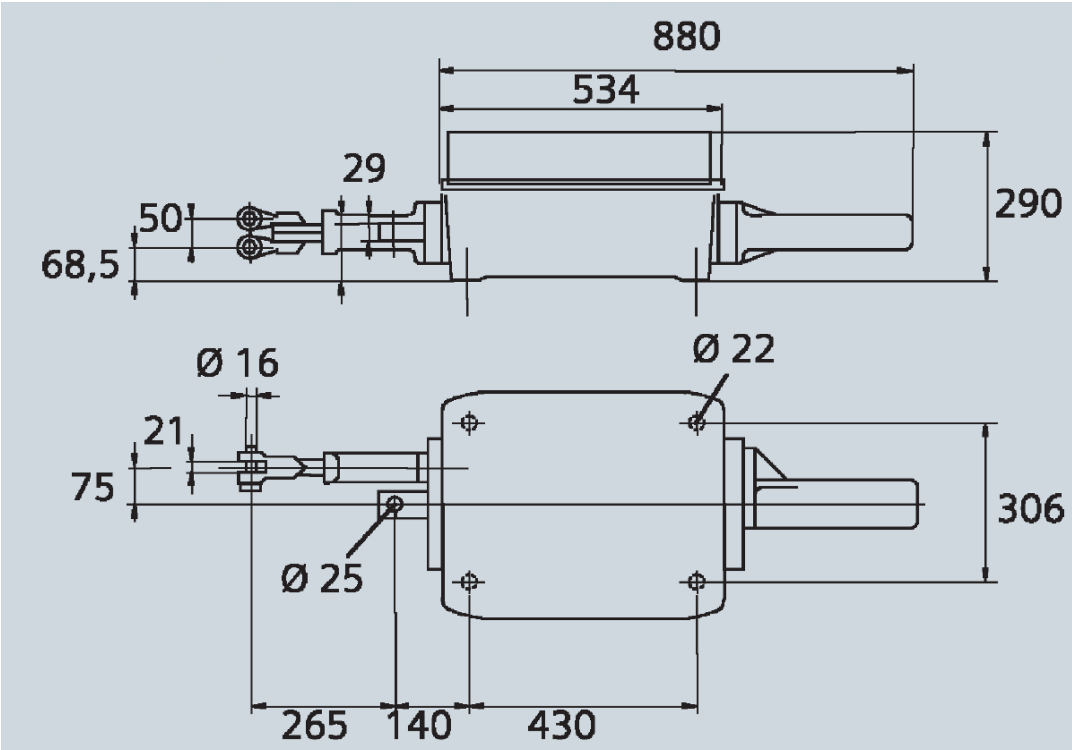


Figure 14 Some important dimensions of S 700 K in mm [13]

2.3.1.2 SWITCHGUARD SURELOCK POINT MACHINE

Switchguard Surelock is another type of point machine designed and manufactured by Siemens. It can be used on both metro and mainline infrastructure. Siemens claims that this point drive system is designed upon a proven technology and modular construction principles are followed by emphasizing its simplicity and strength (Figure 15).

Electric motor, drive system, detection adjustments, escape and control modules are located in a cast iron base. A molded glass reinforced cover is installed on top of the iron base.

Siemens claims that this flood proof point machine is suitable for both metros and mainlines with all switch types. It can be mounted between the rails for metro applications by courtesy of its low profile. This application and the point machine can be examined in Figure 16.

The mean time between failures (MTBF) of the Switchguard Surelock is 39 months and the mean time to repair (MTTR) is 15 minutes as stated in the leaflet of product. Four independently replaceable modules namely motor, drive assembly, escapement and control are contained in its enclosure. Total weight of the machine is 170 kg.

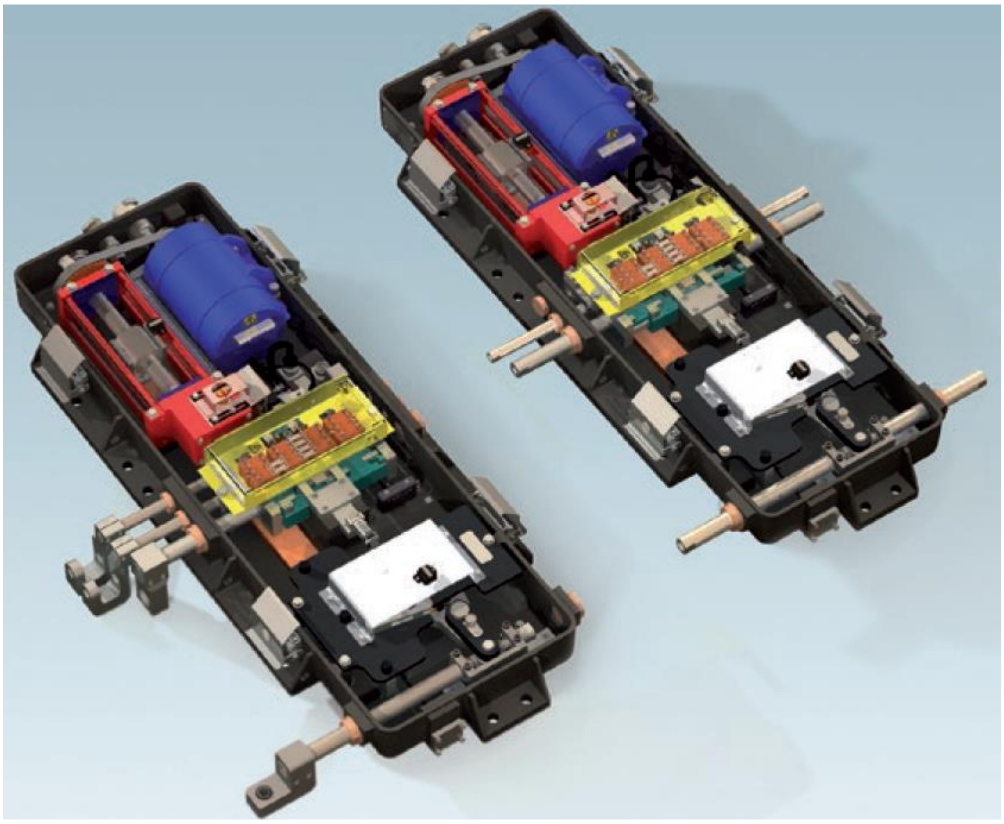


Figure 15 Siemens Switchguard Surelock point machine [14]

The drive, lock and detection rods can be adjusted in order to provide required movement for an easy installation in each individual application. The machine does not need electrical clutches since its motor has mechanical snubbing and also allows constant brush-wear detection. Vandal-proof and lockable plug coupler system is used for all cable connections.

Figure 16 Switchguard Surelock point machine mounted between the rails (the wooden wedges protect the machine from a derailed wheel) [14]

Siemens points out that the primary functions of Switchguard Surelock are:

- To switch the points required positions on demand
- To lock the points mechanically at the end positions
- To detect the closed and locked positions of the points

Siemens also explains the secondary functions of the machine as follows:

- Provide a safe method for hand operation during maintenance or in case of power failure
- Provide overload protection in the drive module
- Prevent ingress of moisture and dust
- Provide flood resistance

- Provide interfaces for condition monitoring system

2.3.2 VOESTALPINE POINT MACHINES

The company Voestalpine has a signaling group offering point operation, locking, monitoring technologies and also diagnostic systems for rolling stock. Voestalpine asserts that they offer innovative solutions to provide safe and efficient rail transport. Their first products were used on tramway lines in Berlin. Later on Voestalpine extended the product range to cover other railway applications as well as tramway networks in Germany and other countries. Then they offered the Unistar point machine series having a modular design with their acquired knowledge from international experience. Some of the point machines including two different types of Unistar series are presented in detail below.

2.3.2.1 AH950 POINT MACHINE

AH950 is a compact, electro-hydraulic type of point machine. It offers to switch the point rails independent from type and gauge of the rail with an external lock. It can be used for both urban and main line traffic.

Voestalpine describes the internal structure of the machine such that it contains an electro-hydraulic point operating unit, a detection module for tracking the final positions of the point blades, connections to an external lock and an interlocking system (Figure 17).

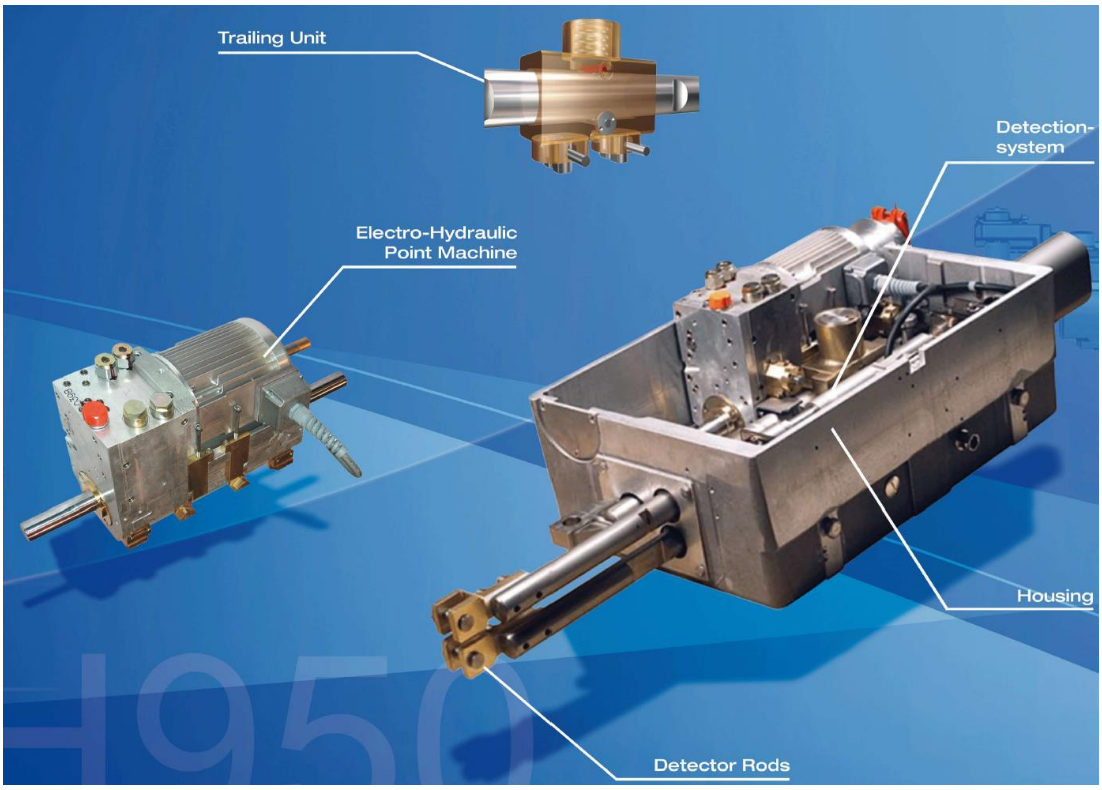


Figure 17 Voestalpine AH950 main parts [15]

Trailable and non-trailable versions of this product are available. It can be used with different supply voltages according to the requirements from the rail operators. This point machine is available as protection degree of IP54 and resists temperature variations (Figure 18).

Voestalpine claimed advantages are:

- Compatible with various interlocking systems
- Compatible with any type of turnouts and different locking systems
- Reduced maintenance requirements
- Low life-cycle costs
- Easy installation and handling
- No wear and tear thanks to hydraulic power transmission
- Modular system configuration and change of hydraulic system on-site

- Maximum safety, reliability and availability under harsh environmental conditions

Figure 18 Voestalpine AH950 installed on the rail line [15]

2.3.2.2 UNISTAR CSV 24 POINT MACHINE

The Unistar CSV 24 is one of the electro-hydraulic point machines designed and produced for grooved rail and flat bottom rail turnouts by Voestalpine. The company emphasizes the availability of this point machine in terms of extremely shortened inspection and maintenance time and also lowest maintenance demands.

Voestalpine indicates that Unistar CSV 24 has the certification of SIL4 (Safety Integrity Level of 4). The machine is claimed to be used in more than 40 countries and exceeding 3000 applications. One major difference of Unistar CSV 24 from many other point machines is a stainless steel housing and it provides good and permanent water resistance because of the special sealing system. The housing contains a mono-block hydraulic system integrated with operating cylinder, motor, prism lock made of high-grade special steel and detector bar with end position contacts. Details of this point machine is presented in Figure 19. The maintenance on the machine is reduced to the minimum and made significantly easy due to its fully modular structure as stated by Voestalpine. The MTTR value of the point machine is equivalent to 15 minutes only.

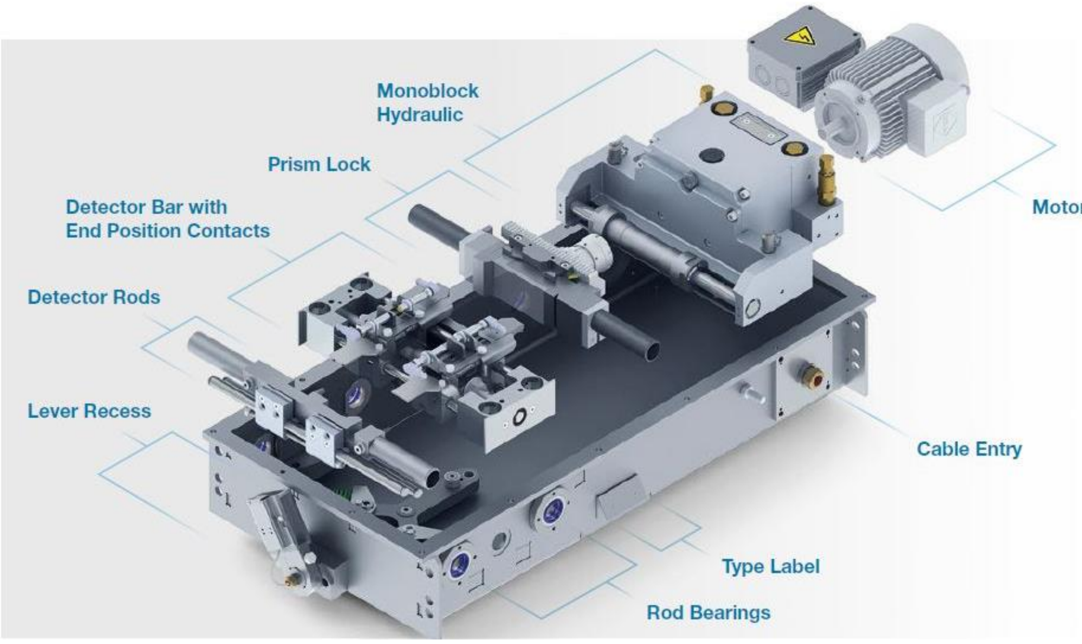


Figure 19 Modular design structure of the Unistar CSV 24 [16]

Voestalpine states that ultra-flat design of the point machine enables to use it for the rails which are low profile light rail vehicles operate on them. This low height architecture allows it to be also used into existing earth boxes without any earthwork.

Unistar CSV 24, which can be seen in Figure 20, is applicable for grooved rail as well as flat bottom rail turnouts of all sizes and types due to its infinitely adjustable tongue throw. Different fixing methods for the installation of the machine are available for various applications and all types of fastening elements are made up of hot dip galvanized steel to ensure a durable corrosion protection.

(a) (b)

Figure 20 Unistar CSV 24 point machine embedded track, 1000 mm track gauge (a) and open track, 1435 mm track gauge (b) [16]

The hydraulic drive mechanism provides a constant pressure throughout the entire throw time and operates at very low noise level as stated by Voestalpine. Various supply voltages are available.

Voestalpine asserts that the system benefits provided by Unistar CSV 24 are listed below:

- Water and sand proof with the protection degree of IP 67
- Extremely low profile having only 180 mm constructional height
- Mono-block hydraulic drive unit without any pipes
- Easy mounting and dismounting
- Visible locking parts
- SIL 4 certified
- Easy access to end position contact
- Trailable

Table 2 Technical data of Unistar CSV 24 point machine [16]

Safety Integrity Class	SIL 4
Installation	Track center or beside the tracks
Turnout type	Grooved and flat bottom rail turnout
Track gauge	Starting with 900 mm
Throwing stroke	38 to 120 mm, adjustable without part replacements
Throwing time	0.5 to 1.5 seconds
Throwing force	Adjustable up to 6000 N
Holding force	Adjustable up to 9000 N
Motor voltage	24 V to 750 V AC and DC, typical 110 V DC, 230 V AC, 400 V AC, 750 V DC
Locking system	Internal prism lock, trailable or non-trailable
Protection class	IP 67

2.3.2.3 UNISTAR HR POINT MACHINE

Voestalpine Signaling introduced the Unistar HR heavy rail series of point machine in 2008. It is put forward that Unistar HR exceeds many railway specifications such as German Railways and American Railway Engineering and Maintenance-of-Way Association (AREMA).

As stated by Voestalpine, these machines are currently in service more than 35 countries for mainline, high speed track, heavy haul, metro and light rail applications even under harsh environmental conditions. The design of Unistar HR has a certification of SIL 4 to prove perfectly reliable operation.

Since the points on the high speed rail lines are longer than that of conventional rails, it may be required to use more than one point machine at the points of high speed railways. This can be achieved by either using more than one point machine or more than one drive unit operated from a central power unit. Obviously throwing strokes of the machines or drive units are different from each other in any case since they are installed in a distributed manner along the points. If a point is operated with multiple point machine configuration, all machines are driven with a central control command and they all complete their operations at the same time. Unlike if the point is arranged by using more than one drive unit, all drive units are operated by the central power unit which takes the command signal from the control center. All point machines or drive units installed at the points of high speed rail lines are locked at the end of operations.

Voestalpine offers Unistar HR which is suitable for such a use and the machine is split into two individual units which are motor unit and DLD (drive, locking, and detection) unit. The motor unit with hydraulic drive has a capability of operating multiple DLD units installed in a turnout, and identical DLD units are applied in the case of distributed drives in a turnout. The DLD unit is mostly installed in the center of the rails and the motor unit right next to the track. The locking device is always integrated within the DLD unit and the unit has an adjustable switch point opening for the operation of different kind of applications. The connection rods are designed to compensate for thermal expansion and contraction of the point rails without affecting the settings of end position. All individual unit boxes are water- and dust-tight certified according to protection class of IP 67. One DLD unit and its motor unit can be seen in Figure 21.

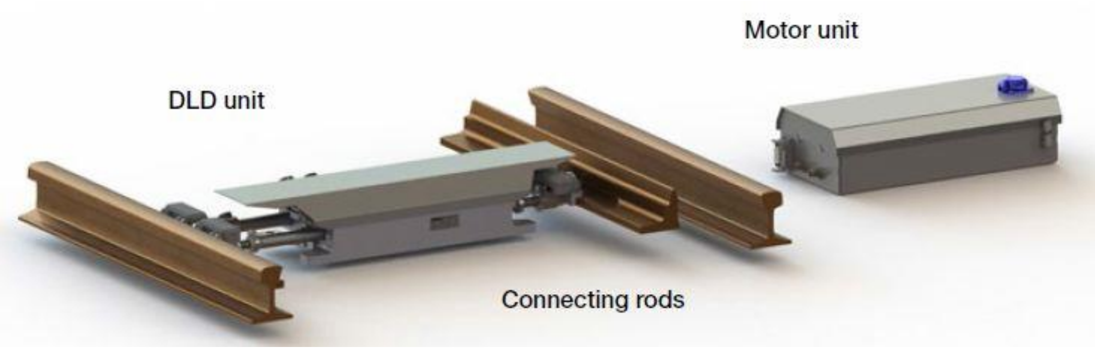


Figure 21 Unistar HR contains two individual units [17]

There are several methods for the fixation of Unistar HR to the track as indicated by Voestalpine. First one is the installation of the units on top of concrete or steel sleepers. There is a patented installation method of Voestalpine on top of concrete sleepers and this avoids introducing the steel sleepers that cause a different behavior on the ballast. The second method is the stock rail fixation between two sleepers. A supporting frame is fixed to the stock rails and point machine modules are mounted on this specially designed supporting frame that keeps the gauge. Another fixation method is to use brackets for simple installation on slab track between adjacent sleepers.

There is an additional end position detection module, Unistar ELP, offered by Voestalpine and it is used between multiple DLD units in a long turnouts or at the tips of the point blades. It has two detector rods to track the open and closed positions of the points. The housing of the ELP unit has almost the same design as the DLD and this reduces the number of different parts in the system because same fixation components and connection rods are used for both DLD and ELP units (Figure 22).

Figure 22 Unistar ELP modules installed between DLD modules [17]

Voestalpine offers a compact version of Unistar HR in conventional design as illustrated in Figure 23. Motor unit and DLD unit are put together in one enclosure box and they are identical with the ones used in the Unistar HR. Installation of Unistar HR compact is more conventional outside the track and this alternative is price competitive as stated by the company. Installation of the machine can be either left or right hand without any change on it. It can be manually operated by the help of manual hydraulic pump.

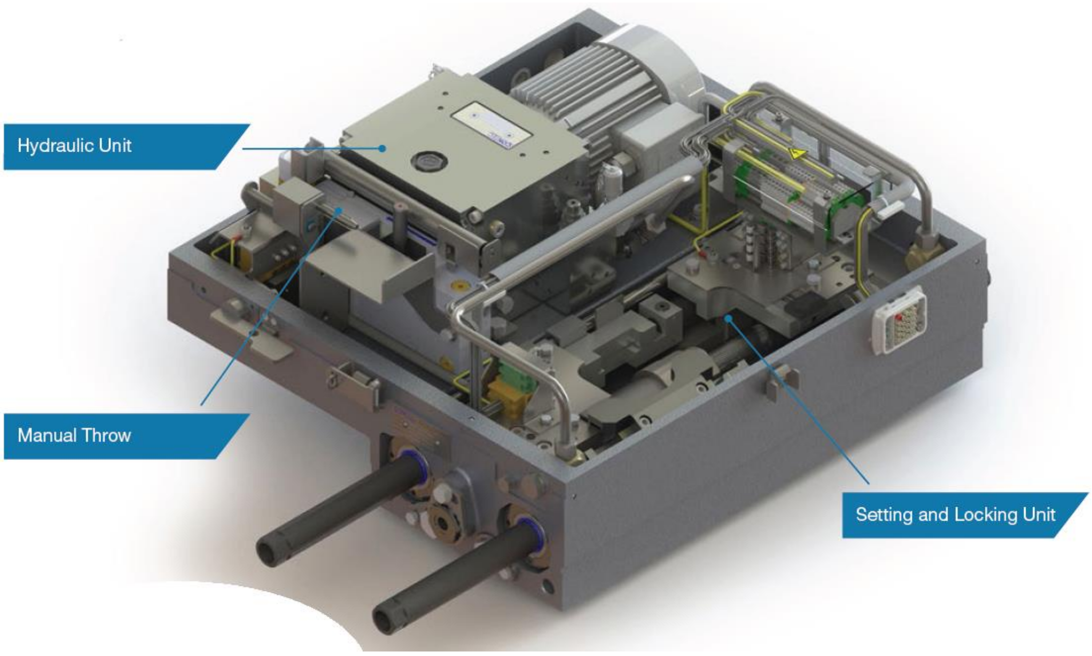


Figure 23 Compact version of Unistar HR [17]

Voestalpine offers two different drive systems to meet customer requirements; one is electro-hydraulic and other one is electro-mechanic. At the beginning of the design phase of Unistar HR, integration of both drive systems was taken into consideration and main components such as housing, locking device and detector system are remained identical which can be seen in Figure 24. As indicated by the producer, the electro-mechanic drive is integrated into the DLD unit and this makes it the most compact point machine all over the world.

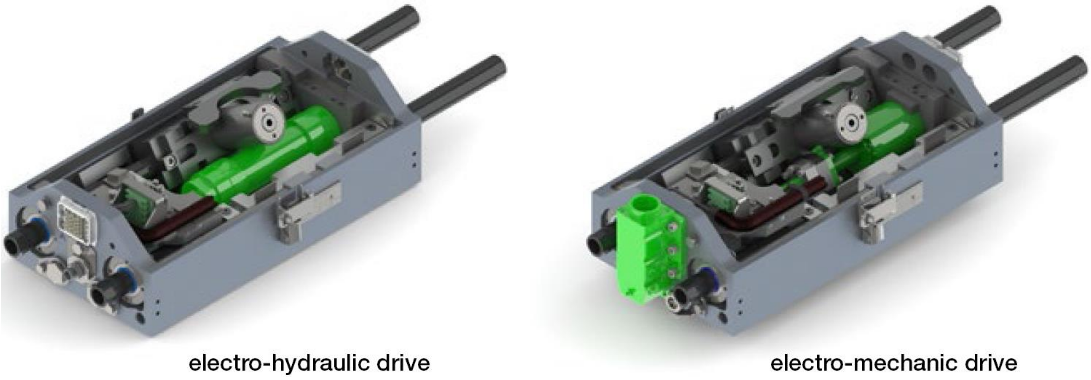


Figure 24 Electro-hydraulic and electro-mechanic drive systems [17]

The comparison of these two drive systems is given Table 3 below.

Table 3 Comparison of electro-hydraulic and electro-mechanic drives [17]

	Unistar HR	**Unistar HR EM**
Motor location	In a separate module	Integrated in DLD unit
Driving force	Up to 17000 N	Up to 11000 N
Manual operation	Quick pumping action Alternative: cranking	Cranking
Multiple drives	- One motor unit operates all DLD units distributed in a turnout - Manual operation at a single point - Only one interface to the interlocking - No need to separate controls	- Each DLD unit in a turnout has its own motor - Manual operation at each individual motor unit - Up to 3 units require one interface to the interlocking - Distributed local controllers
Interlocking integration	Any motor voltage possible and readily available	110V DC, 230V AC and 400C AC are available, other voltages are on request

Voestalpine emphasizes the advantages of the compact modules of Unistar HR allowing for unrestricted arrangement in the track. Both points and crossings can be driven with one standardized DLD unit. A central power module with one mono-block hydraulic unit installed beside the track drives all DLD units. Technical data of Unistar HR is presented in Table 4.

Table 4 Technical data of Unistar HR point machine [17]

Safety Integrity Class	SIL 4 according to DIN 50126, 50128 and 50129
MTBF	> 500000 hours
MTTR	< 20 minutes
Environmental conditions for the operation	-40 to +80 ^{o}C, humidity up to 95%, solar radiation tested with 1120 W/m^2
Protection class	IP 67
Weight: electro-hydraulic	DLD unit approx. 80 kg, motor unit approx. 50 kg
Weight: electro-mechanic	DLD unit with integrated motor approx. 85 kg
Throwing time	1 – 5 seconds
Throwing force	Adjustable up to 17000 N
Throwing stroke	60 to 163 mm, adjustable
Motor voltage	24 – 750 V AC or DC
Locking system	Internal prism lock, trailable or non-trailable
Fixation to track	- Concrete or hollow steel sleeper, - Stock rail fixation, - Sleeper fixation
Turnout type	All type of turnouts

Finally, Voestalpine Signaling declares the benefits of Unistar HR point machine in brief as follows:

- All components are mounted at one level in the box and there is no hidden parts and this provides decreased inspection times
- More than one DLD unit can be powered by just one mono-block hydraulic unit

- Units are waterproof with the protection degree of IP67
- It can be used for all types of turnouts
- Unit weights are low and no need for lifting equipment
- In case of metro and tunnel applications, the motor unit can also be installed at the tunnel wall
- MTTR values are minimized
- Switching times are fairly low

2.3.3 VOSSLOH POINT MACHINES

Vossloh is a company providing different range of products in the rail infrastructure industry. The product portfolio of the company covers signaling systems and it offers a wide range of safety products including point machines for different applications like conventional tracks, urban transport systems, high-speed and heavy load transport in order to improve safety on the rails. Some of the point machines designed and produced by Vossloh are listed below.

2.3.3.1 EASYDRIVE-I POINT MACHINE

Easydrive-i point machine is the first of its kind at Vossloh. The aim of this electro-hydraulic point machine is to operate the switch points safely and to ensure the end positions of the point blades as stated by the company.

The machine is directly installed on the concrete or wooden bearers or on the slab track between the rails (Figure 25). It has two individual units to be installed at the turnout switch points. The external hydraulic unit is installed next to the track but it does not need any specific area, since it can be installed in very narrow spaces. This also provides the maintenance staff to work on it safely near the track while operating the machine manually. The external hydraulic unit can also be mounted on the wall especially in the tunnel applications.

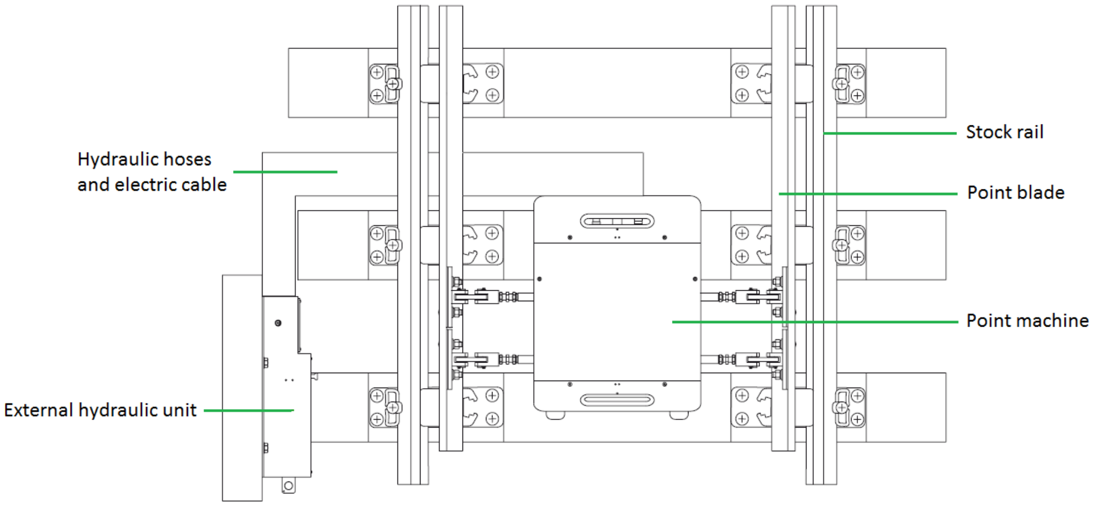


Figure 25 Schematic view of Easydrive-i installation [18]

Vossloh can propose both trailable and non-trailable versions of Easydrive-i according to requirements of railway operators. Trailable versions can be operated without any damage when the point is trailed accidentally or by any reason. The producer claims the machine needs a very low maintenance and it provides a high level of reliability. Level of safety of the machine is measured as SIL4.

The components of the point machine and external hydraulic unit is tabulated in Table 5, separately and they can also be seen in Figure 26 and Figure 27.

Table 5 The list of components of the point machine and external hydraulic unit [18]

Components of the point machine	Components of the hydraulic unit
• A hydraulic jack • Two operating rods	• A hydraulic unit • An information screen

• Two detection rods • A trailing cartridge • Clamping detection modules • Position detection modules • Fast plug connectors • A protection cover	• A secured access to the manual operation • An emergency hand pump • Fast plug connectors • A main connector • Easydrive-i electrical connector • A hydraulic hand pump lever

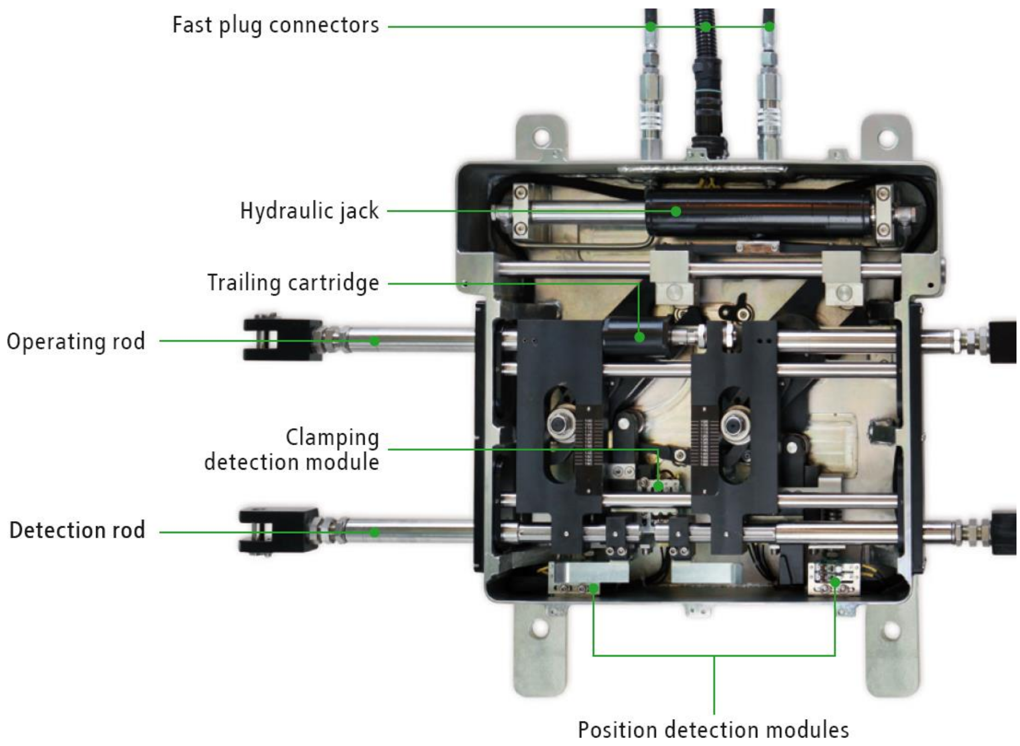


Figure 26 Inside view and components of Easydrive-i point machine [18]

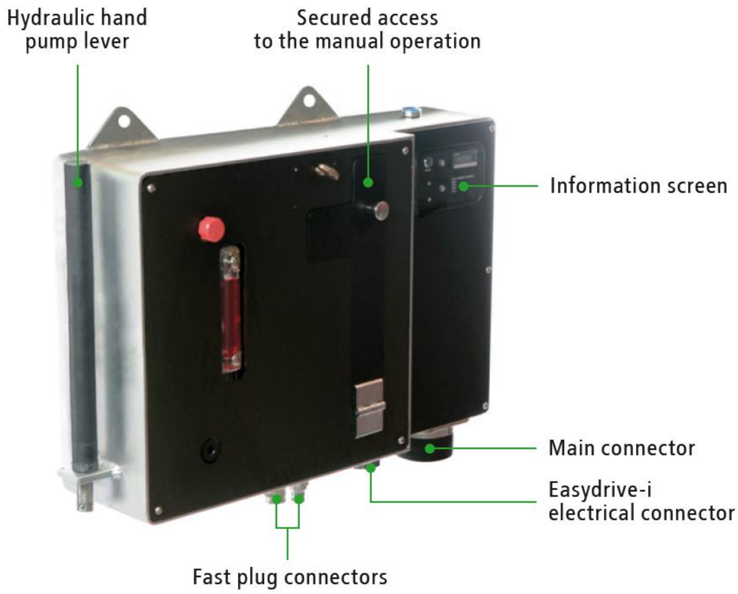


Figure 27 External hydraulic unit of Easydrive-i point machine and its components [18]

The external hydraulic unit generates pressure to move the jack and hereby the point is operated with the operating rod. The machine locks the point blades at the end positions and activates the position detection modules.

The technical specifications of Easydrive-i are presented by the company in its leaflet and can be found in Table 6.

Table 6 Technical specifications of Easydrive-i point machine [18]

Length	535 mm
Width	620 mm (off rods)
Height	145 mm
Weight	95 kg
Stroke	100 to 160 mm, adjustable on site
Operating force	4000 N
Operating time	< 2.5 seconds

Protection rating	IP 67
Safety integrity level	SIL4

2.3.3.2 MCEM91 POINT MACHINE

The electro-mechanical point machine model MCEM91 is designed and produced by Vossloh and it provides the point operation, its locking and detection at the end positions. The company states that this point machine is suitable to operate the points of all types of tracks including conventional lines, metros, service lines, high speed lines and heavy haul networks.

Figure 28 Vossloh MCEM91 type of point machine [19]

Vossloh claims that this product is used in more than 30 countries. TCDD is also one of the users of this point machine in the high speed lines between Ankara and Konya (Figure 29). They are also installed in conventional train lines between Mersin and Toprakkale [19].

Figure 29 Multiple drive integrated into high speed line turnout in Turkey [19]

Drive function of the machine is achieved with a single driving rod connected to adjustable arm on the machine. Throwing stroke of the machine can be adjusted by the driving arm length due to its rotary motion at the exit of the machine. The adjustable driving arm sweeps at an angle of 60 degrees during the throwing operation and it is locked at the end positions. Vossloh indicates that an additional internal anti-veering device is positioned in the machine to resist vibration effects caused by passing rolling stock.

The company Vossloh defines the components of the machine as follows:

- An electric motor according to required voltage, can be AC or DC
- An internal torque limiter device

- A gear box
- A locking mechanism at the end positions
- An adjustable driving arm connected to driving arm head
- A switch equipped with power and control contacts
- A manual emergency drive lever
- An electrical water proof connector, offered as optional
- A locked cover

The machine is adoptable to many types of tracks and compatible with different bearers including concrete or metallic bearers and concrete slab track. Technical characteristics of this point machine given by Vossloh can be seen in the following table below.

Table 7 Technical characteristics of MCEM91 point machine [19]

Throwing stroke	100 to 260 mm, adjustable
Maximum load during drive	4000 to 10400 N
Switching time	3.5 to 4.8 seconds
Weight	< 100 kg
MTBF	Over 30 years
MTTR	0,61 hours
Protection index	IP55 or IP67 (optional)

2.3.3.3 MCEM91T POINT MACHINE

The MCEM91T is the trailable version of the MCEM91 point machine and it is equipped with a trailing disc allowing point trailing. It includes additional components such as a trailing disc and trailing detection device (optional). The application and installation flexibility as well as drive, locking and detection principles are exactly the same as the MCEM91 point machine. This trailable version is also in use on the conventional line between Mersin and Toprakkale in Turkey.

Figure 30 Vossloh MCEM91T type point machine which is trailable version of MCEM91 [20]

Required trailing force can be adjusted in the factory as stated by Vossloh. In case of trailing occurs on the switch point, the machine needs a manual drive to reconcile the internal mechanism with the driving arm.

Some of the technical characteristics of this version are slightly different and presented in Table 8.

Table 8 Technical characteristics of MCEM91T point machine [20]

Throwing stroke	115 to 260 mm, adjustable
Maximum load during drive	4000 to 9000 N
Trailing force	9250 N for stroke of 220 mm 10700 N for stroke of 160 mm
Maximum trailing speed	50 km/h
Switching time	3.5 to 4.8 seconds

Weight	130 kg
MTBF	Over 30 years
MTTR	0,67 hours
Protection index	IP55 or IP67 (optional)

2.3.4 THALES POINT MACHINES

Thales is a group company having point machines as one of the rail signaling equipment.

2.3.4.1 L710H POINT MACHINE

The L710H electro-hydraulic point machine is designed and manufactured with the experience of Thales in Arnstadt, Germany. Thales states that this design with protection class of IP67 allows nearly wear free operation and it brings very long life time for the product. Thales also highlights the field proven operation of the machine even in harsh environment conditions like strong water, humidity and sand. It can perform more than one million movements in those extreme conditions before overhaul. An internal lock is installed in the point machine and a hand crank is provided for manual operation (Figure 31).

(a) (b)

Figure 31 General view (a) and inside (b) of the L710H point machine [21]

As claimed by Thales, there are several advantages and benefits of the L710H point machine. First one is the availability of the product for every point type and gauge. It is also available for every AC electrical interface with the interlocking. Optionally DC electrical interface can also be realized. Another advantage is that it does not need maintenance between overhauls. Operation capability of the machine in harsh environmental conditions is indicated as another benefit of the product. Moreover technical parameters of the machine can be adjusted and customized according to customer requirements.

Finally technical features of L710H point machine can be summarized in Table 9.

Table 9 Technical features of L710H point machine (adopted from [21])

Power supply	380/220 V AC with 700 W Other AC or DC power supply can be provided on request
Throwing force	Adjustable up to 6000 N
Retaining force	Adjustable up to 9000 N
Throwing time	Can be customized, typically < 6 seconds
Stroke	Can be customized for any type of point and gauge
Application type	Can be applicable for every point type

Lock type	Internal point lock is included
Life time	More than 1 million throwing before overhaul
Installation	Suitable for both right- and left-hand
Trailability	Can be configured as trailable or non-trailable
Protection class	IP 67
Electrical interface	Suitable for all common electrical interfaces like 4-wire, 7-wire, etc.

2.3.4.2 FIELDTRAC 6343 L826H POINT MACHINE

FieldTrac 6343 L826H is a new generation electro-hydraulic point machine of Thales. Integration of the machine in the sleeper and individual blade control instead of control rods are the main alterations of this latest version compared to previous products of Thales. It is claimed that the machine works with high efficiency and needs no maintenance. Another advantage is that the installation of this machine on right-hand or left-hand turnouts is possible with no need to change anything on it (Figure 32).

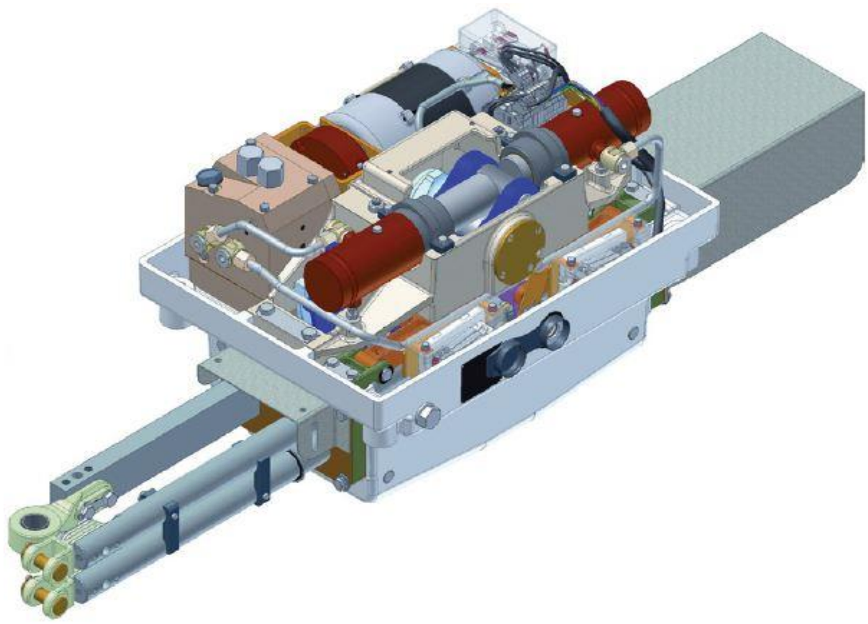


Figure 32 Inside view of the FieldTrac 6343 L826H point machine [22]

The design of FieldTrac 6343 L826H allows some major parts of the machine to be pre-assembled. This contributes to decrease installation time at the production plant and offers low maintenance costs with increased availability at the field of operation.

An enclosed dustproof electric motor is used to drive the pump generating pressure for the movement of specified cylinder. The cylinder rotates the throwing disc at an allowed constant angle and this is repeated for every operation of the machine. In this manner, the throwing time is not affected by the stroke and remains constant. Thales asserts that this diminishes the required force and hence the wear during the operation. The throwing disc is connected to the operating rod that moves the point blades. Two detector bars are used to check the correct positions of the point tongues at the end of the movement. The hydraulic part of the machine is a closed system consisting of an oil container, a reversible radial piston pump, check valves, adjustable relief valves and two hydraulic cylinders.

Technical parameters of the FieldTrac 6343 L826H shared by Thales is presented in Table 10.

Table 10 Technical parameters of FieldTrac 6343 L826H point machine [22]

Power supply	400 V, 3-phase, 50 Hz
Power input	Approximately 700 W
Throwing force	Adjustable between 2000 N and 7000 N, depends on the stroke
Retaining force	Adjustable between 7000 N and 9000 N for trailable version Approximately 30 kN for non-trailable version
Throwing time	Approximately 5 seconds, independent from the stroke
Stroke	Adjustable between 80 mm and 260 mm

2.3.5 ALSTOM POINT MACHINES

Alstom's trackside signaling equipment including point machines is the major part of an overall rail system for reliable and continuous operation. Alstom has alternative point machines for different applications. Two different kinds are presented below.

2.3.5.1 P80 POINT MACHINE

P80 is an electro-mechanical point machine that is applicable for main lines, freight lines and metros with single switch and double slip switches. Right hand and left hand installations are possible for both trailable and non-trailable versions. Therefore the machine is declared as highly configurable and can be adapted to many different customer applications. In addition to this, as stated by Alstom, water resistant construction and a wide range of operating temperature maximizes the flexibility of P80 point machine which is presented in Figure 33.

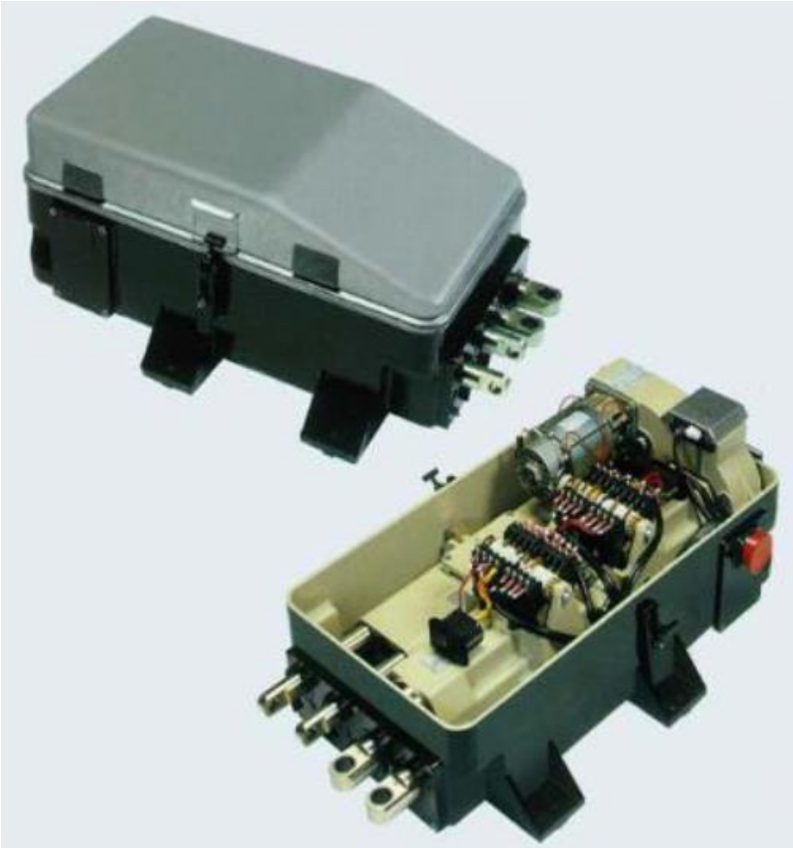


Figure 33 Alstom P80 point machine and inside view of it [23]

There are two independent rods to operate the blades and two independent rods for the detection of blade end positions. Alstom claims to make a point of achieving higher level of safety by performing double lock for both open and closed point blades. P80 point machine, in order to extend the lifetime, cuts off motor power automatically when it encounters an obstacle during operation. It provides a hand crank for manual operations in case of maintenance or unexpected situations. The trailable version of the machine has also capability of restoring to normal operating conditions without operator intervention after trailing occurs (Figure 34).

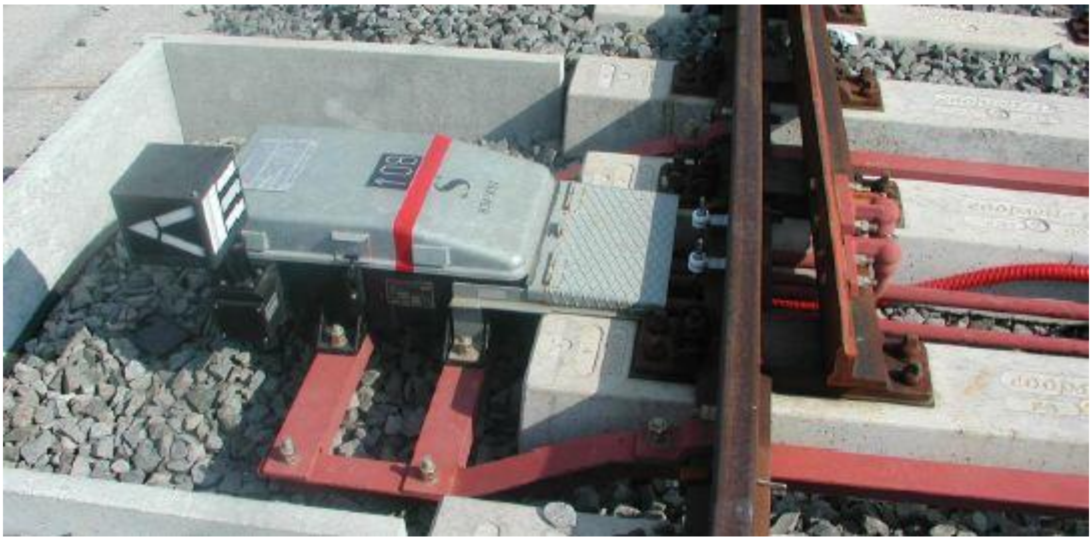


Figure 34 The photograph of P80 point machine installed near the track [23]

Another benefit of the machine for customers, indicated by Alstom, is that the machine does not need periodic maintenance and internal adjustment. This is achieved by a spring loaded device inside the machine instead of a traditional clutch system. An internal locking device which is certified up to 180 km/h is also contained in its casing.

Number of installed P80 point machine is more than 17000 over 30 years worldwide including Turkey, Eskişehir-Balıkesir line. The machine is configured for the use of in Turkey according to requirements of TCDD and this configuration is called as P80-T. Technical features of P80-T are provided by Alstom are presented in Table 11.

Table 11 Technical features of P80-T that is configured for use in Turkey [23]

Product Number	Right: DTR2000004015 Left: DTR2000004018
Operating voltage	3 x 380 V AC 3 x 220 V AC
Current drawing during operation	1.5 A at 380 V AC 2.6 A at 220 V AC

Operating time	5 seconds
Throwing stroke	150 mm, fixed
Throwing force	>= 550 kg
Trailing force	770 to 950 kg
Allowed train speed	180 km/h
Locking type	Internal
Operating temperature	-40^{o}C to +70^{o}C
Humidity	0 to 100%
Weight	240 kg
Size	913 x 565 x 334 mm (length x width x height)

2.3.5.2 HY-DRIVE POINT MACHINE

Hy-Drive is an electro-hydraulic point machine offered by Alstom and mainly used in turnouts with more than one drive. Alstom asserts that this is a cost effective solution for multi-point turnouts and therefore suitable for use on high speed lines. As stated by the company, the lifetime of the machine is about 30 years or 1 million operations. Alstom also states the point machine is certified for trains travelling on direct branch at a speed of up to 305 km/h.

Hy-Drive point machine is a fully modular system consisting of two locking and detection units installed at the tip of turnout, an external power pack and a number of hydraulic back drives. The number of hydraulic drive units depends on geometry of the turnout. This is the main reason why this solution is considered as a cost effective solution for the turnouts requiring multiple drive which can be examined in Figure 35. Moreover this kind of modular solution allows easy installation, replacement and check of all units.

Figure 35 Hy-Drive point machine solution installed on a multiple drive turnout [24]

Alstom claims that Hy-Drive point machine can meet many customer configurations and performance requirements because it offers different options for the operation stroke and cylinder dimensions.

The machine is commercially in service since 1994 and more than 900 turnouts mainly in Italy and United Kingdom are equipped with this machine as stated by Alstom.

Technical parameters of Hy-Drive point machine are shared by Alstom and presented in Table 12.

Table 12 Technical parameters of Hy-Drive point machine [24]

Pump power supply	144 V DC, 230 V DC, 230 V AC 50 Hz
Switching time	4 to 10 seconds *
Throwing force	Up to 10000 N, adjustable
Trailing force	40000 N
Tip opening	115 mm

Back drive stroke	Factory configurable between 36 and 110 mm
MTTR	< 20 minutes
Reliability	30 years / 1 million operations
Operating temperature	-40^{o} C to +70^{o} C
Protection class	IP 54 compliance with EN60529
Compliance to standards	EN 50129, EN 50126, EN 50121-3-2, EN 50125-1, IEC 600068, EN 50155, EN 61373, NF F 16-101-102
*depending on power supply and length of turnout	

2.4 PATENT REVIEW

Patents are critical intellectual property rights for any competitive business. They conserve valuable assessments if retrieved, analyzed and utilized appropriately. Therefore patent research is an important step of a literature review to demonstrate continued progress throughout the history and is an indicator for future development of new products.

In this study, the patents retrieved directly related with the point machines and their sub functions are researched to learn the contributions made by authors, researchers, experts and companies. It is easy to say that the patents about the point machines have been started to retrieve before 1950s. However as the patent collection worldwide is growing rapidly, retrieval of these precious sources has become complex and exhaustive. In the scope of this thesis study, some of the patents retrieved directly related with the point machines and their sub functions are included and the list of these patents is presented in Appendix B. There are many patents retrieved in different countries and the languages are also different. Therefore all patents could not be studied in detail but the general information is obtained from their abstracts. As a consequence of the patent research, it is not difficult to express that the inventions mainly focus on operating mechanisms for the railway points, locking the switch blades and complete systems for the operation of railway points. Besides, there are some inventions about the trailing feature of the machines and examining the end positions of the point blades.

2.5 MOTIVATION OF STUDY

In the last decades, especially in the last few years, rail systems are becoming more and more popular all over the world, particularly in the European Union and also in Turkey. Rising traffic demand, congestion, noise, risk of life safety, field use, energy consumption and climate change are some of the major issues that all humanity are facing. This calls for the railway sector to get the better of these challenges and to achieve a more competitive, safer and resource-efficient transport system [25].

Turkey has also become aware of this shift from road to rail in transportation sector to increase rail's share in the freight and passenger transport market. Research and development activities in railway systems therefore have been started helping the railway sector to be domestic in majority and to play a broader role in transport market. The first studies have been focused on the trains itself to introduce quieter, more reliable, more comfortable, energy-efficient and most importantly completely domestic railway systems. These efforts have found out innovative and competitive solutions at a lower cost.

Introduction of better trains to the transport market requires a reliable rail network including signaling and infrastructure equipment. In addition to the development studies on rail vehicles, at the same time similar efforts have been started to improve signaling and infrastructure in Turkey. Research and development studies have focused in the fields which are thought as the part of critical technology. For example traction systems including the traction motors, traction inverters and convertors are considered as the brain of a rail vehicle, the studies therefore have been focused firstly on these equipment. Similarly train control and management system is another important issue for railway engineers in Turkey at the signaling side.

It is known that turnouts are one of the most critical elements of rail construction as they lead the railway traffic. The only movable part of the rail track is the turnouts and this makes them an important part of rail network. Depending on this, point machines are the crucial devices for quick operation and locking of switches, and thus they play an important role in safe and efficient running of trains.

Procurement of these important devices in Turkey is responsibility of Turkish State Railways, in short TCDD, by a majority. Significant number of these point machines were imported from other countries by TCDD until today. With the recent technological improvement on the railway systems in Turkey, it is considered that developing completely domestic point machines is an important target in the near future. These point machines are thought as one of the critical components of the railway signaling and infrastructure.

The motivation of this study is to perform research about modern point machines which already exist in the market and includes detailed investigations on some of them. Then their constructional and operational characteristics are compared for the purpose of preparing background and guidelines for the development of a novel and domestic point machine.

CHAPTER 3

INVESTIGATIONS OF DIFFERENT RAILWAY POINT MACHINES

This chapter covers detailed studies and analysis on different types of point machines currently used at the railways operated by TCDD in Turkey. These studies basically consist of kinematic and simple force analysis of driving mechanisms, locking mechanisms and detection methods. The investigations also include the constructional details of these point machines such as casing materials, motors, power packs, operational voltages, power transmissions, driving mechanisms, locking mechanisms, electrical contacts, throwing times, strokes and forces.

Although there are numerous point machines with different brands and types currently used at the railways in Turkey, this thesis study contains four of them. In order to avoid making advertisement or smearing the brand names, the investigated point machines are entitled by the letters like point machine A, point machine B and so on.

3.1 INVESTIGATIONS ON POINT MACHINE A

The point machine A is an electro-hydraulic point machine including a hydraulic power pack, driving mechanism, locking mechanism, terminal block and contacts. All these components are installed in a molded aluminum casing. Additionally there is one driving rod having rectangular cross section to move the point and two detector bars having circular cross sections to supervise the correct position of the point blades individually. General inside view of point machine A is shown in Figure 36.

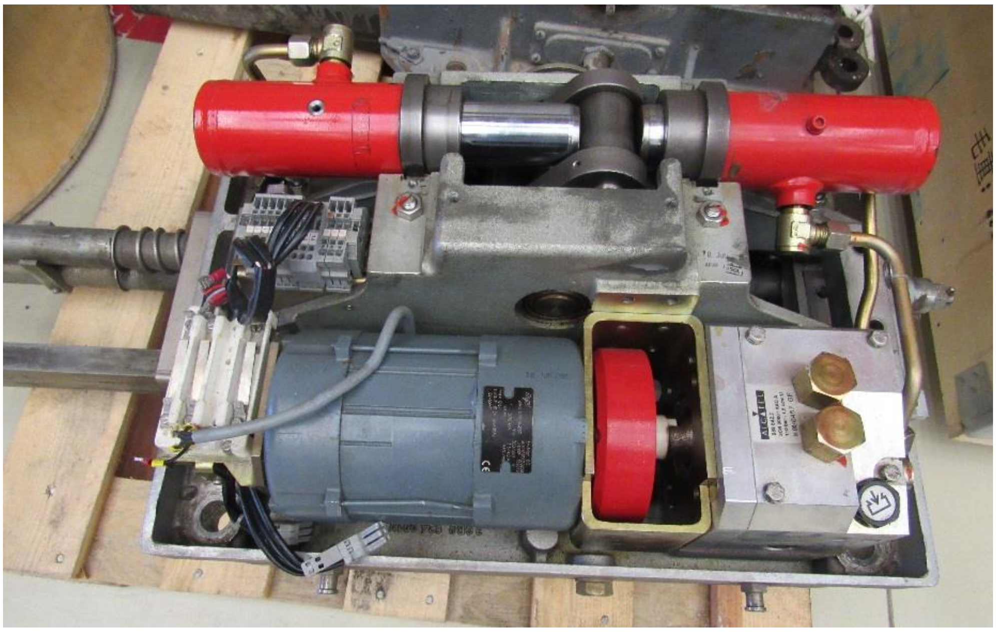


Figure 36 Photograph of inside view of point machine A

The hydraulic power pack contains a 3-phase electric motor which has the power of 700 W. The motor can be operated with a voltage of 380 V or 220 V. The current drawn by the motor is 2.3 A under the potential of 380 V and 4.0 A under 220 V. Rotational speed of the motor is 930 rev/min. It has a dustproof enclosure with the protection degree of IP 54.

The compact hydraulic block consists of a reversible radial piston pump, an oil tank, check valves and adjustable relief valves. The electric motor is connected to this hydraulic block with a flexible coupling and thus it drives the pump to generate the pressure. Two hydraulic cylinders are installed on a cast aluminum structure which is fastened on the casing to move the throwing disc. These cylinders are connected to the exit of hydraulic block by the aluminum pipes having an external diameter of 10 mm. The radial piston pump pressurized the hydraulic fluid with a flow rate of 1.5 cm^3/rev up to 110 bars to move the assigned cylinder. Figure 37 shows the photograph of hydraulic power pack including electric motor and compact hydraulic block.

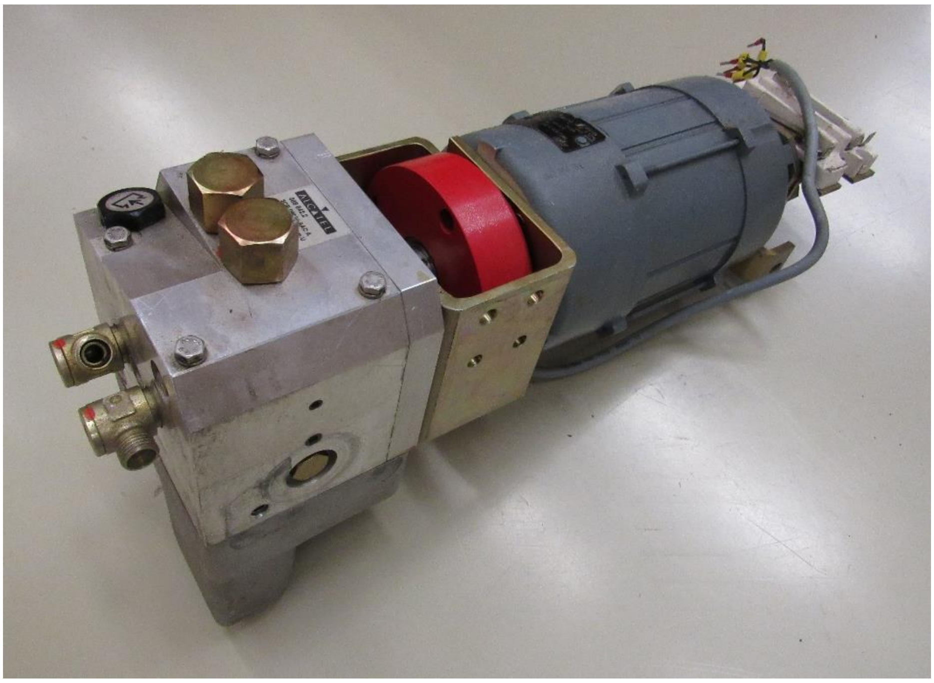


Figure 37 Photograph of hydraulic power pack driven by electric motor

Driving mechanism of the machine has been analyzed in detail. First of all, kinematic structure of moving parts are observed and a kinematic model related to driving mechanism is obtained. Dimensions of the parts and constant distances between parts are measured on the mechanism with the help of a tape measure and a caliper. This model is represented as a simple sketch and parametric dimensions are shown in Figure 38. All of this kind of schematics in the content of this study are drawn by the author.

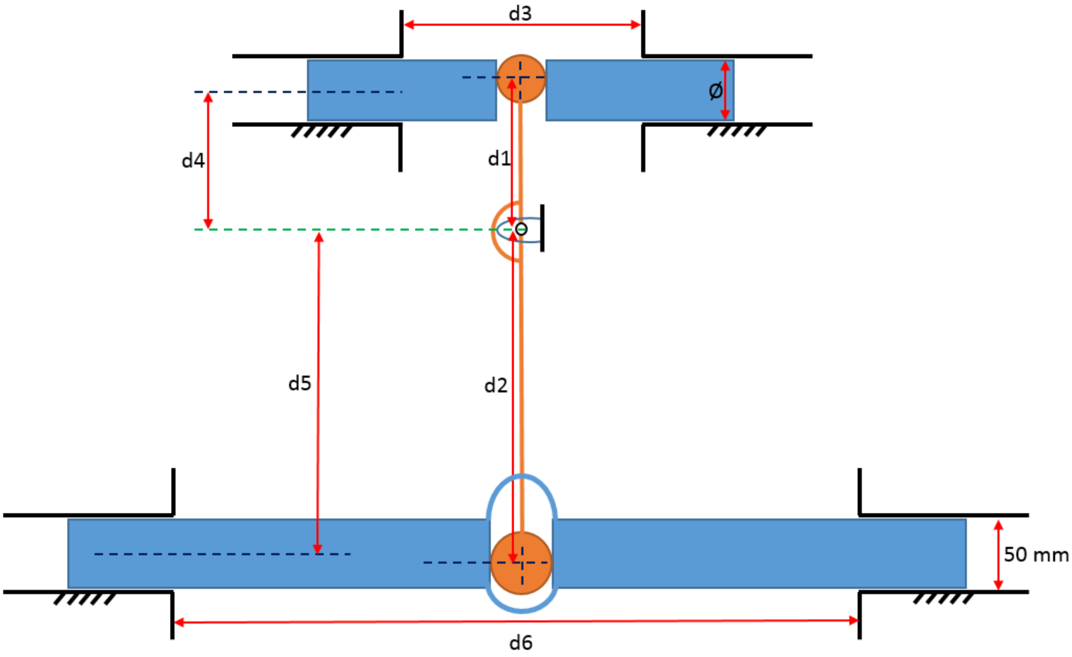


Figure 38 Representative model of driving mechanism

In Figure 38, dimension d1 represents the distance between center of rotating disc and center of cylinder standing between hydraulic cylinders. Dimension d2 shows the distance between center of rotating disc and center of lower cylinder generating the motion of driving rod. This dimension can be adjusted to move the lower cylinder on a radial direction of the rotating disc. The nearest distance between two piston bodies is represented by d3. Vertical distance between the center of rotating disc and hydraulic cylinders is shown as d4. Similarly, d5 indicates the vertical distance between center of rotating disc and center of driving rod. Finally the distance between two beds of driving rod from the inner sides of casing is represented as d6 and the diameter of hydraulic cylinders is shown as Φ.

All dimensions and distances, except d2, shown in Figure 38 are constant. d2 is the only variable dimension on the mechanism and it is used to adjust the throwing stroke of the machine. There is a scale on the rotating disc corresponding the related stroke values to adjust. The scaling numbers on the rotating disc which are changing in between 80 and 260 are presented in Figure 39.

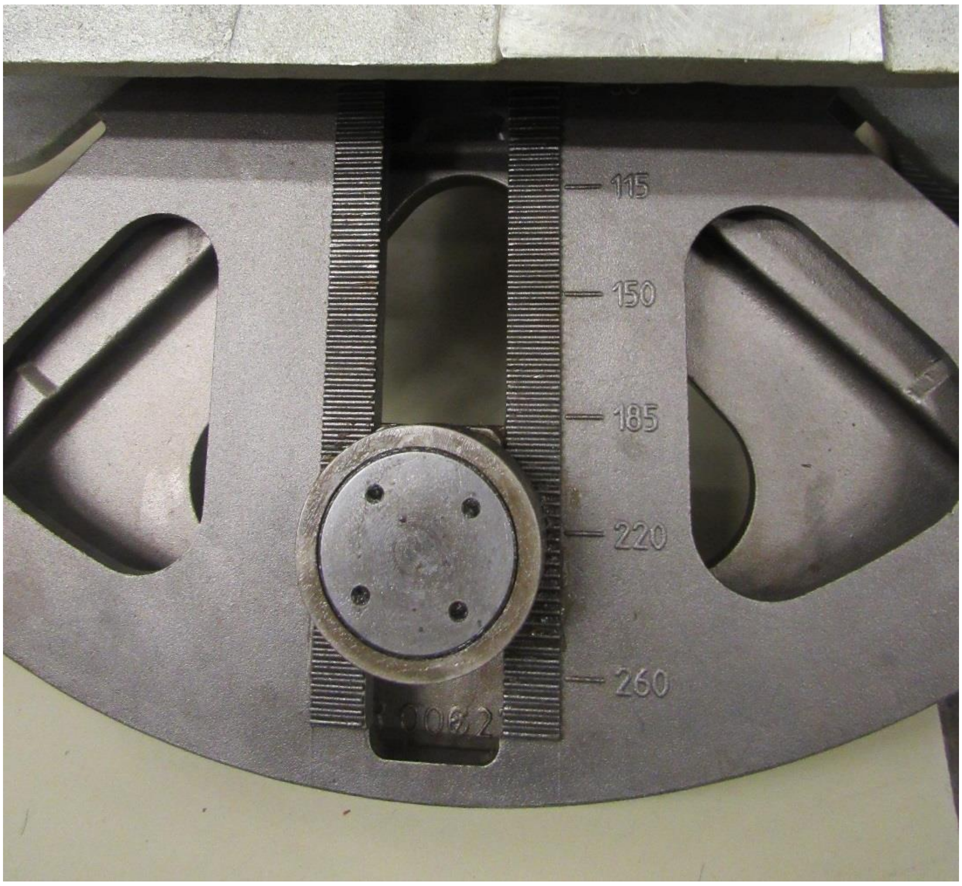


Figure 39 Photograph of scaling numbers on the rotating disc to adjust the stroke

The numerical values of these representative dimensions and distances are measured as d1=50 mm, d3=134 mm, d4=43 mm, d5=153 mm, d6=455 mm and Φ=45 mm. The only variable dimension d2 can change from 60 to 195 mm.

The mechanical parts of the driving mechanism are numbered and these numbers represent the links of the mechanism one by one. The link numbers are shown in Figure 40.

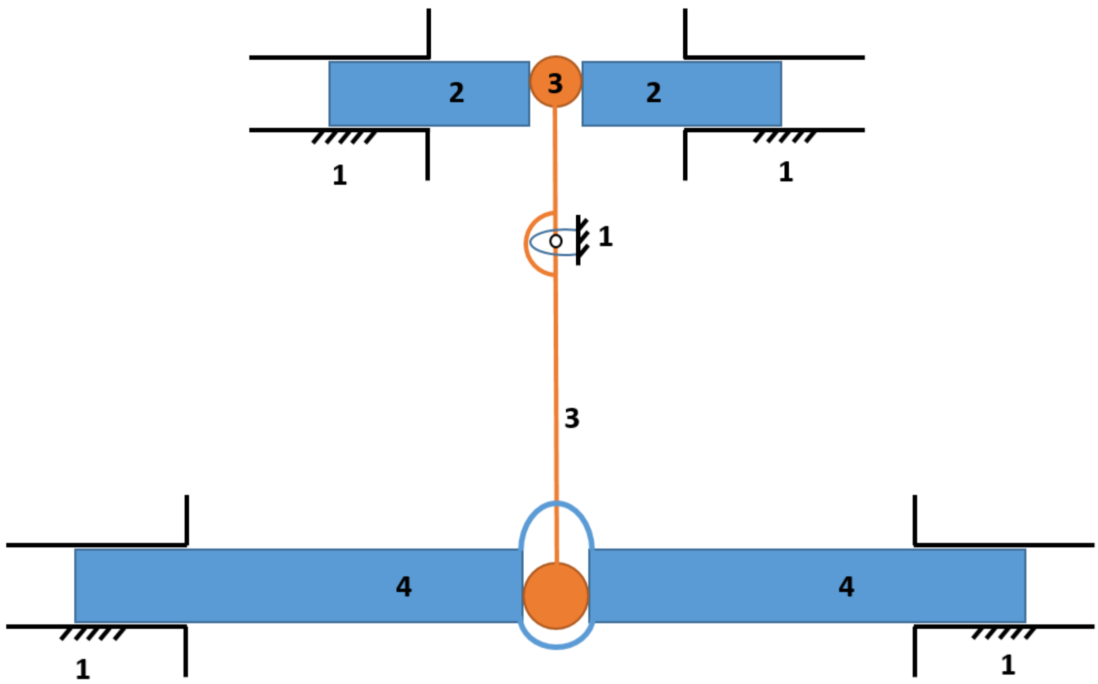


Figure 40 Representative schematic model showing the links of driving mechanism

The link number 1 shown in Figure 40 represents the ground, namely molded casing and other parts which are fixed on it. The link shown by 2 represents the hydraulic pistons. Although they are two separate cylinders, they move together in synchronous and no one do work against each other if the friction between piston and its cylinder is neglected. Therefore it is assumed that they show the property just like a single link and both of them are numbered as 2. Link 3 and link 4 show the rotating disc and driving rod, respectively.

The kinematic joint types between these links are described in Figure 41. There are three types of joints in this driving mechanism. First one is the revolute joint between link 1 and link 3, which is shown as R13. Second type of joint is prismatic joint between link 1 and link 2. There is also another prismatic joint between link 1 and link 4. These are represented as P12 and P41 respectively. The last type of kinematic joint is cylinder in slot and this joint type is observed between link 2 and link 3, indicated by CS23. There is also one cylinder in slot type of kinematic joint between link 3 and link 4 and it is described as CS34.

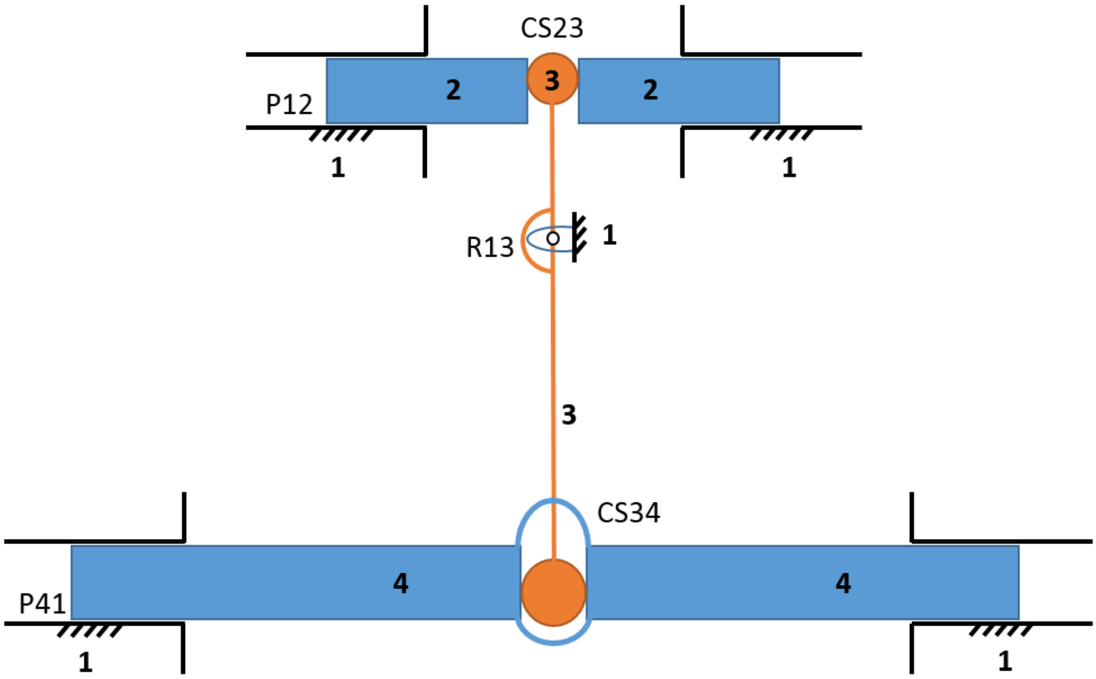


Figure 41 Kinematic joint types between the links

Describing the kinematic links, their dimensions and joints between them, the next step is defining the variable dimensions and angles which are changing during the movement of driving rod. Figure 42 shows an arbitrary position of the driving mechanism while it is in motion.

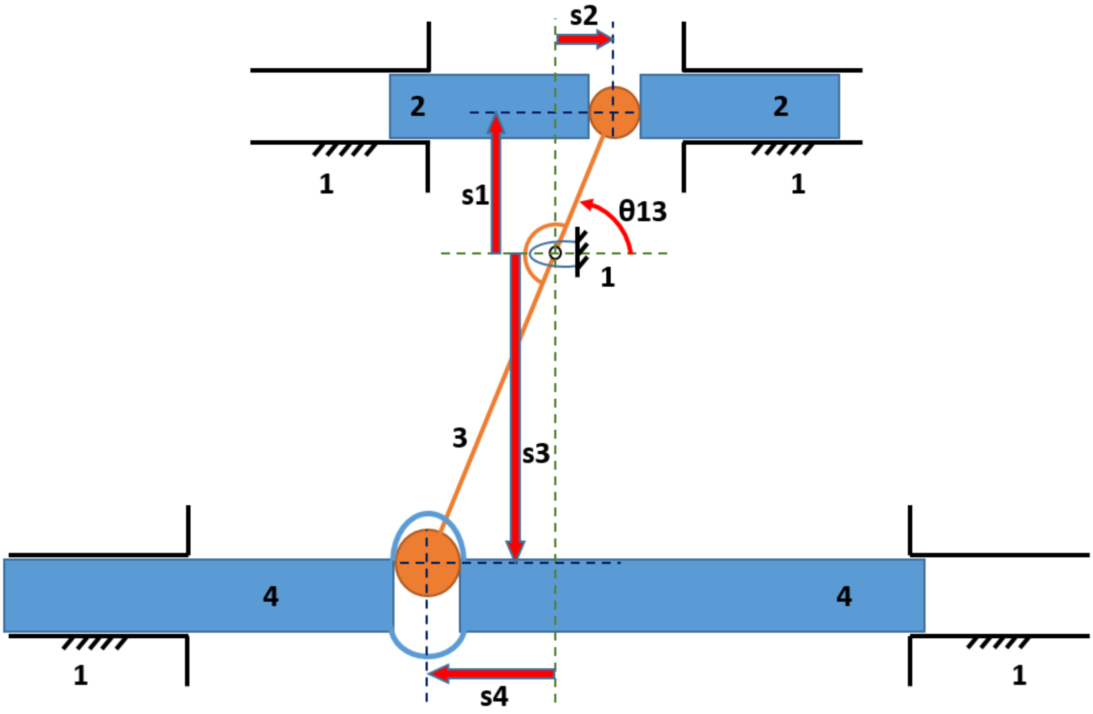


Figure 42 An arbitrary position of the driving mechanism

Variable dimension s1 in Figure 42 shows the vertical distance between the center of rotating disc and the center of cylinder standing between hydraulic cylinders. Horizontal distance between these two centers are shown as s2. The dimension shown by s3 represents the vertical distance between the center of rotating disc and the center of lower cylinder generating the motion of driving rod. Similar to s2, s4 shows the horizontal distance between these two centers. The only angular variable is indicated as θ13 and it is the angle of link 3 with the horizontal axis. These dimensions are shown with arrows since they are directional quantities. Directional identification is important to analyze the mechanism.

Before going into details of kinematic analysis, some basic parameters and equations are presented.

Since the driving mechanism moves in a planar space, degree of freedom of the space:

$$\lambda = 3 \tag{3-1}$$

As shown in Figure 40, number of links:

$$l = 4 \tag{3-2}$$

As shown in Figure 41, total number of kinematic joints:

$$j = 5 \tag{3-3}$$

Degree of freedom of the mechanism is calculated by using the general degree of freedom equation:

$$F = \lambda(l - j - 1) + \sum_{i=1}^{i=j} f_i \tag{3-4}$$

Where degrees of freedom equal 1 for revolute and prismatic joints, and 2 for cylinder in slot. Therefore total degrees of freedom of each joint is found as:

$$\sum_{i=1}^{i=j} f_i = (2x1) + (1x1) + (2x2) = 7 \tag{3-5}$$

Degree of freedom is numerically found by using equations (3-1), (3-2), (3-3) and (3-5):

$$F = 3(4 - 5 - 1) + 7 = 1 \tag{3-6}$$

Number of independent loops is calculated by using the following formula:

$$L = j - l + 1 \tag{3-7}$$

And it is numerically calculated by using equations (3-2), (3-3) and (3-7):

$$L = 5 - 4 + 1 = 2 \tag{3-8}$$

This means that two independent loops can be formed to analyze the driving mechanism. These loops can be seen in Figure 43 and written in vector form in equation (3-9) and (3-10).

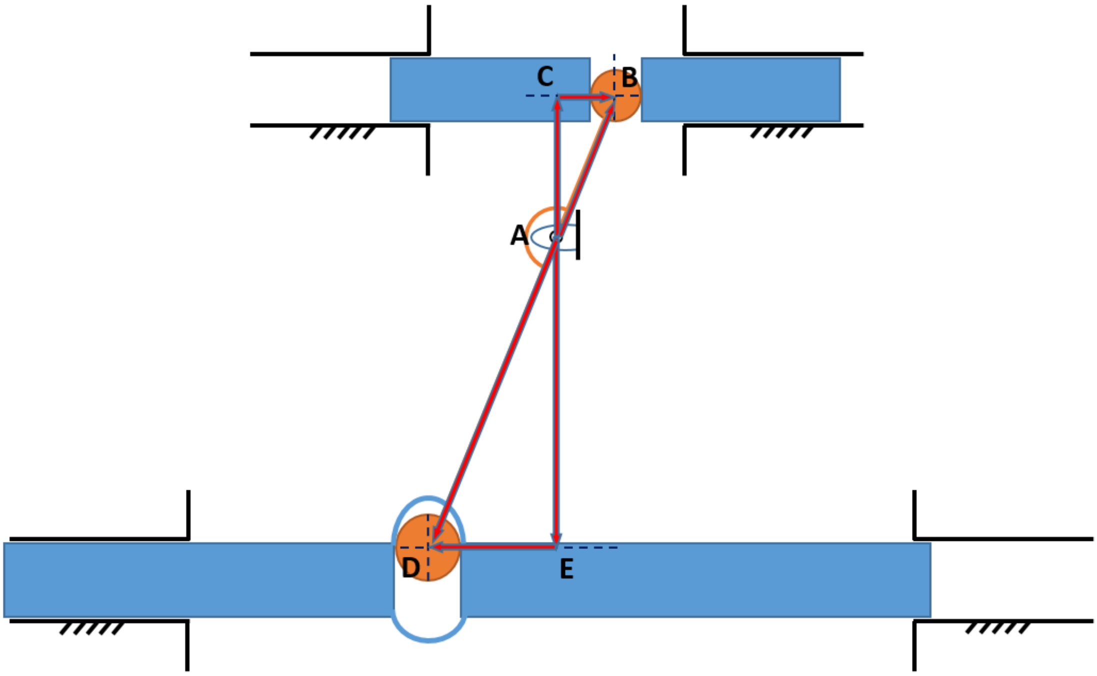


Figure 43 Representative schematic model showing the independent loop closures

$$\overrightarrow{AB} = \overrightarrow{AC} + \overrightarrow{CB} \tag{3-9}$$

$$\overrightarrow{AD} = \overrightarrow{AE} + \overrightarrow{ED} \tag{3-10}$$

Vector equations (3-9) and (3-10) can be represented by complex numbers and may be split into their real and imaginary parts to start the kinematic analysis. Alternatively and more easily, similar triangles ACB and AED may also be used to solve the unknown variables in this analysis.

In order to do force analysis on driving mechanism, free body diagrams of the links are drawn one by one. Figure 44 presents the free body diagram of link 2 representing the hydraulic cylinder. F_i represents the input force on the hydraulic cylinder applied by the hydraulic fluid and F32 shows the reaction force of the link 3 on the link 2 at an arbitrary point. The moment created by the input and its reaction force is balanced with the reaction forces of hydraulic piston on the cylinder and this moment can be represented by two forces having equal magnitudes but opposite directions. These forces are shown as F_y12. The dimension between these reaction forces are measured and described as d7 for the parametrization.

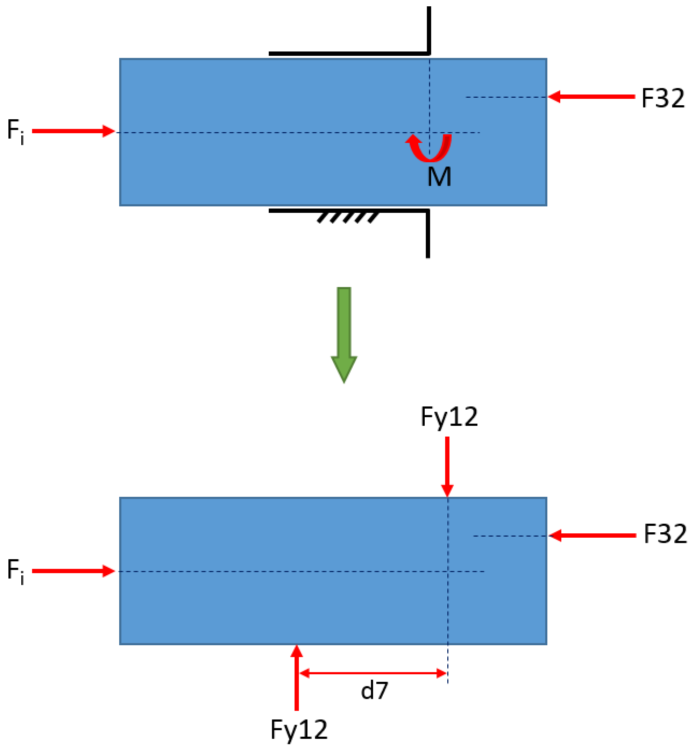


Figure 44 Free body diagram of link 2

Figure 45 presents the free body diagram of link 3 and applied forces on this link. F23 represents the reaction force of link 2 on the link 3. Similarly F43 shows the reaction force of link 4 on the link 3. Reaction force of main structure on the link 3 is presented as F_x13.

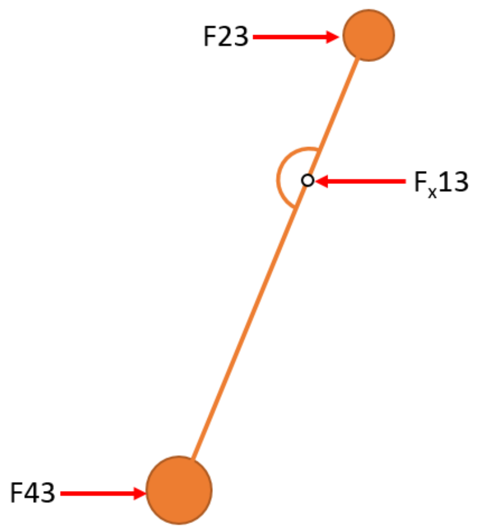


Figure 45 Free body diagram of link 3

Finally the forces on the driving rod are identified in Figure 46. Reaction force of rotating disc on the driving rod is shown as F34 and the reaction force of point blades on the driving rod is represented as F_o. These forces create a moment on the link 4 and this moment is balanced with the reaction forces created by slides. Two forces of equal magnitude are placed at the reaction points in opposite direction and shown as F_y14 to create a couple moment to counter-balance the moment created because F34 and F_o are not collinear.

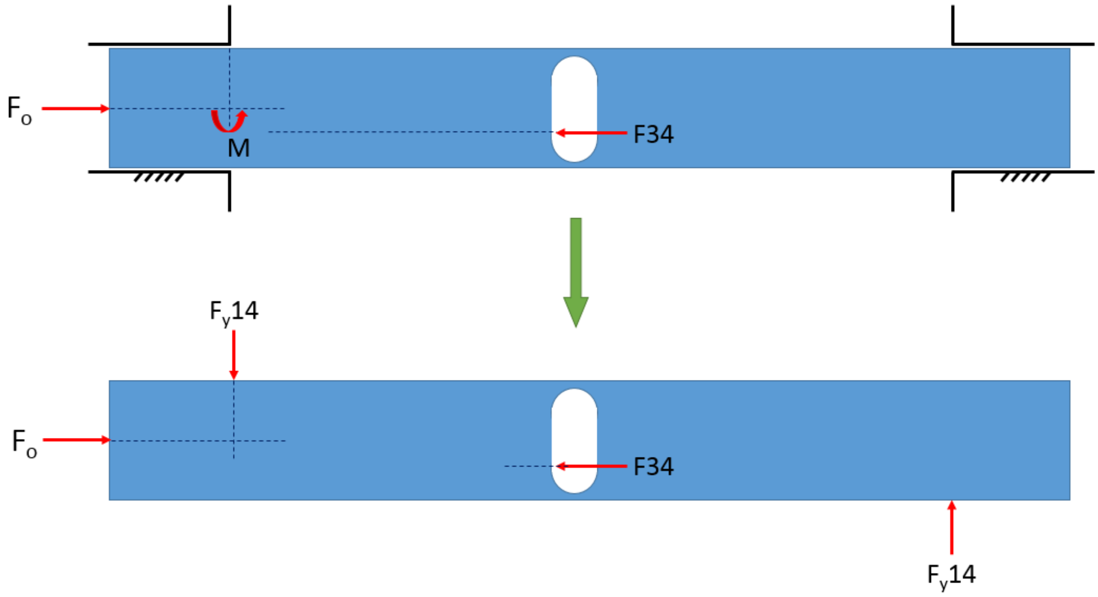


Figure 46 Free body diagram of link 4

After describing the links, joints, constant and variable dimensions, loop closure equations and free body diagrams of the kinematic links; a Matlab code presented in Appendix C.1 is written to perform a position and static force analysis.

Speed of the pressurized hydraulic cylinders defined with “s2_dot” is found as 14.6 mm/s. Operation time of the machine appears as about 5 seconds by knowing the distance between hydraulic cylinders and the diameter of cylinder standing between hydraulic cylinders. The throwing time is directly related with the speed of electric motor, flow rate of the pump and piston diameter. Since these parameters are constant, the throwing time of the machine is also constant and is not affected by the stroke.

On the other hand, the stroke of the machine “s4” is adjusted by changing the “d2” dimension. The stroke of the machine can be adjusted in between 87 mm and 285 mm. For example the minimum stroke is found when d2 is equals to 60 mm and the maximum stroke appears when d2 is adjusted as 195 mm. Figure 47 shows the output position of the driving rod in operation time of 5 seconds. The motion of the driving mechanism shows a symmetric manner with respect to the vertical axis and the variable dimensions on Figure 42 are described by taking the vertical position as the starting point of the motion. Because of these reasons the plot presented in Figure 47 shows the whole period of operation of the mechanism between -2.5 and 2.5 seconds.

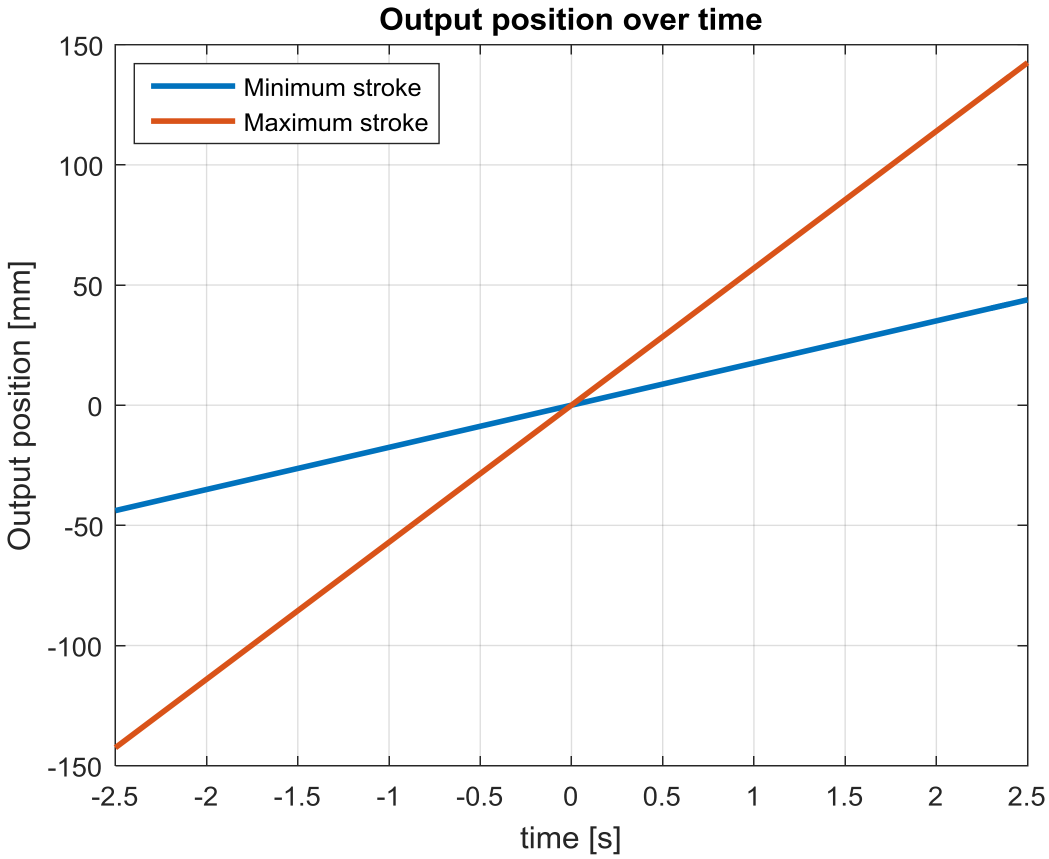


Figure 47 Maximum and minimum throwing strokes of Point Machine A

Figure 48 presents the output position of driving rod with respect to input position applied by the hydraulic cylinders for the maximum and minimum stroke values. The slope of the curves indicates the ratio of how many times the distance taken by driving rod is increased with respect to the input motion of hydraulic cylinders. To illustrate, the slope for the minimum stroke value of the machine is found as 1.2. Similarly, it is found as 3.9 for the maximum value of stroke. This means that the increase rate of gain obtained from this driving mechanism in terms of throwing distance changes between

1.2 and 3.9. On the other hand, there will be a reduction in the throwing force at the same ratios as a result of conservation of energy.

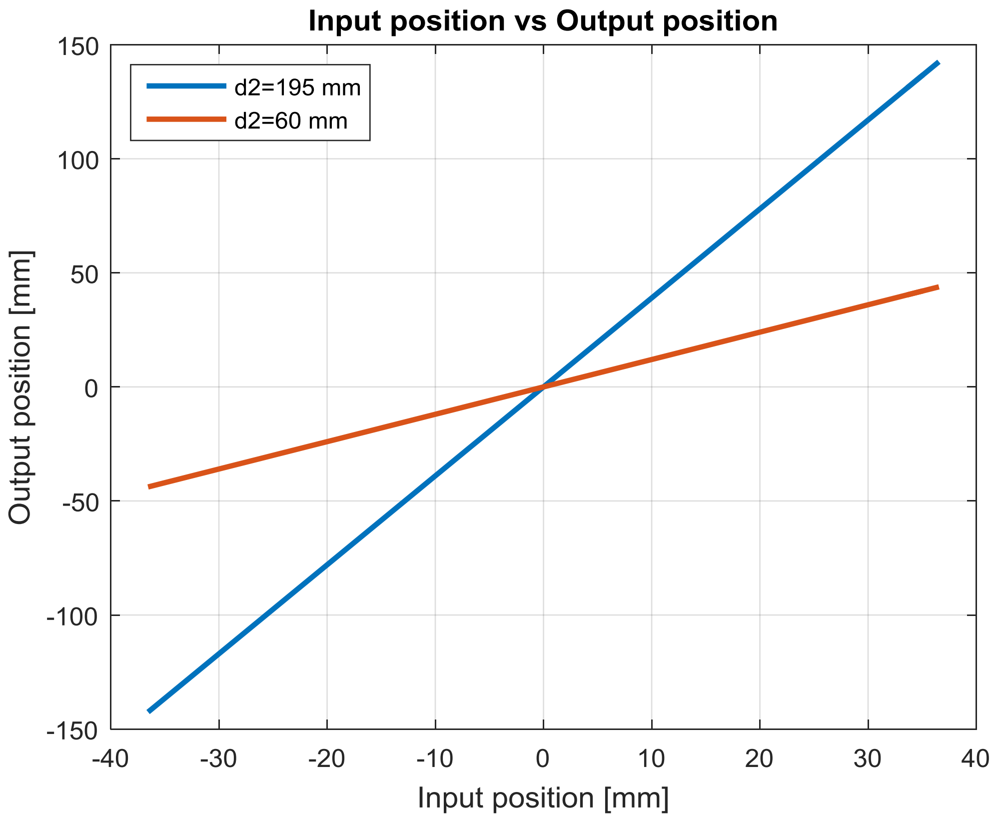


Figure 48 Output position of driving rod with respect to input position

The force applied by the pressurized fluid on the hydraulic cylinder indicated by "F_i" is found about 17.5 kN. Since it depends on the piston area and applied pressure by the pump, input force does not change. This force is transferred to the driving rod by the help of rotating disc. The output throwing force depends on the dimension "d2" of link 3. Throwing force is inversely proportional with adjustable dimension "d2". For example, the maximum throwing force appears as about 14.58 kN for the minimum d2 dimension equaling 60 mm and the minimum throwing force is found as about 4.49 kN for the maximum d2 equaling 195 mm. The rate of change of force can be obtained by dividing the input force by the throwing force. Although the applied input force is constant, the ratio of change of force is calculated between 1.2 and 3.9 due to the changing throwing force.

There are some frictional forces at the joints and mechanical contacts while the mechanism is in motion. Since there are radial bearings or bushings at the revolute joints and low frictional linear bearings at the prismatic joints, these force are negligibly small compared to operational forces of the machine. For example, the frictional force at the rectangular linear bearing between the driving rod and the casing of the machine is measured by using a force measurement device. This measurement is repeated ten times in order to be sure that the measurements are coherent. Figure 49 shows a photograph taken during one measurement. The frictional force at the linear bearing was measured as 40 N at average while it is moving. The maximum force is measured as 70 N at average and it is observed at the impending motion of driving rod.

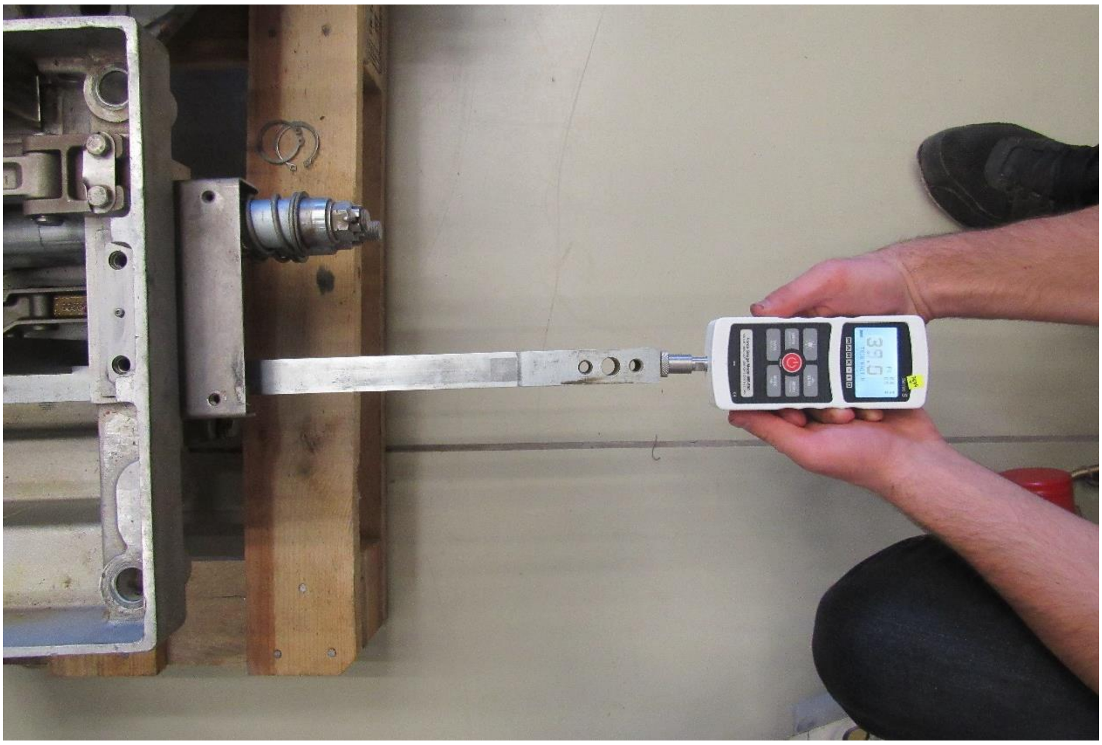


Figure 49 Force measurement at the linear bearing

As described at the beginning of this chapter, there are two detector bars having circular cross sections to control the correct position of the point blades one by one. One of them is mechanically connected to tip of the near point blade and the other one is connected to tip of the distant point blade by the help of a mechanical linkage. When the blades of the point come to one of the end positions and the engagement occurs with the stock rail, a locking mechanism is activated automatically at these positions. Indeed the locking mechanism locks the two detector rods which are mechanically connected to point blades. In this way the motion of the point blades is prevented and the point is locked. The reason why there are two detector rods is to control both of the point blades independently. The locking mechanism does not work if one the detector rods, in fact the point blades, is not in the desired position. It works only when both of the point blades are in the desired position.

The locking mechanism of the machine is designed like a spring-preloaded four-bar parallelogram mechanism and two of them are used to lock the point blades at each end positions. Figure 50 shows the schematic view of these two four-bar mechanisms that are placed opposite to each other and two detector rods. These two locking mechanisms are independent from each other and they are activated at each end position of the blades separately.

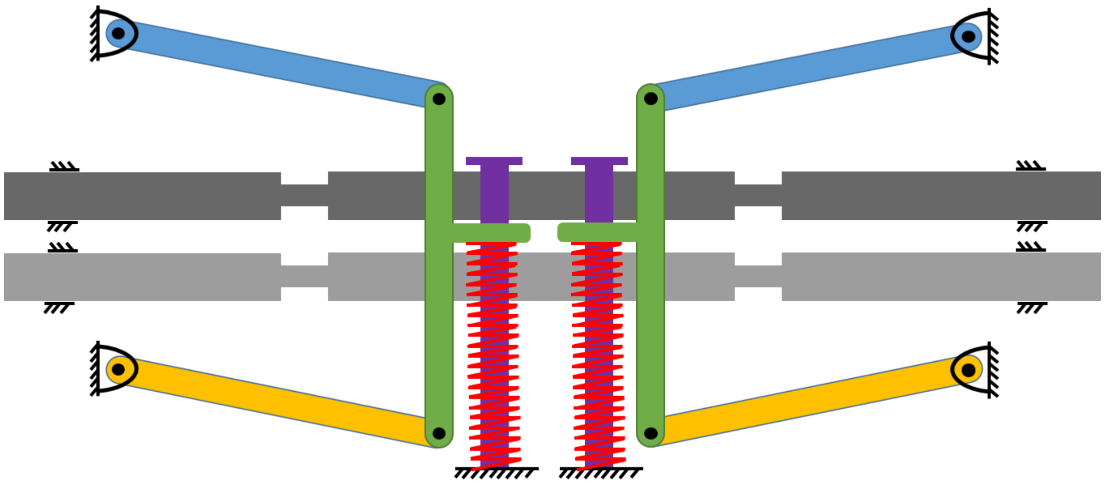


Figure 50 Schematic representation of locking mechanism

Figure 51 shows the unlocked position of locking mechanism together with the rotating disc driven by the hydraulic cylinders. The rotating disc shown as link number 3 continuously in contact with the extension of revolute joint between link 6 and link 7. Therefore it pushes the link 6 downward and compresses the springs shown by color red while the machine is throwing the point blades. Depending on the motion of point blades, the two detector rods indicated by numbers 8 and 9 slide into the linear bearings at two ends since they are connected to the tips of the point blades.

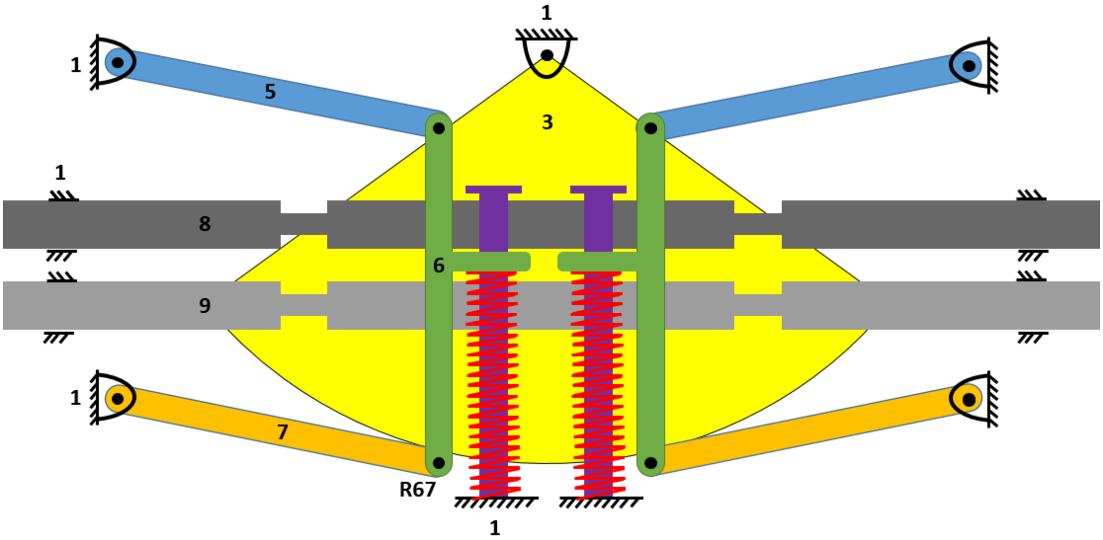


Figure 51 Schematic representation of locking mechanism together with rotating disc

Additionally these two detector rods pass through the link 6 shown in Figure 52. There are two circular openings merged into each other on the link 6. Diameter of these openings are 40 mm and the two detector rods having 35 mm diameter can easily move in these openings while the machine is throwing the point blades.

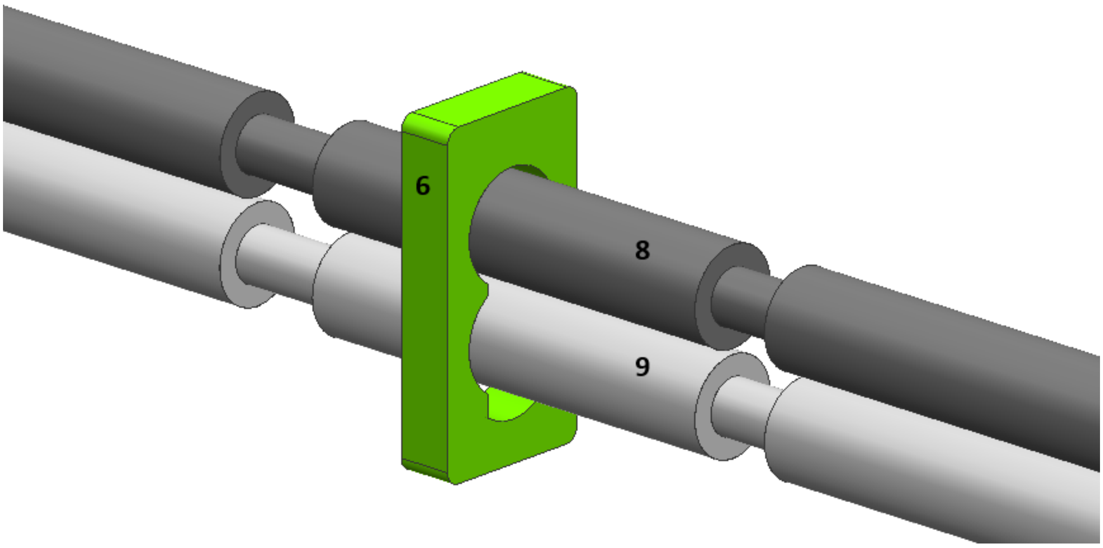
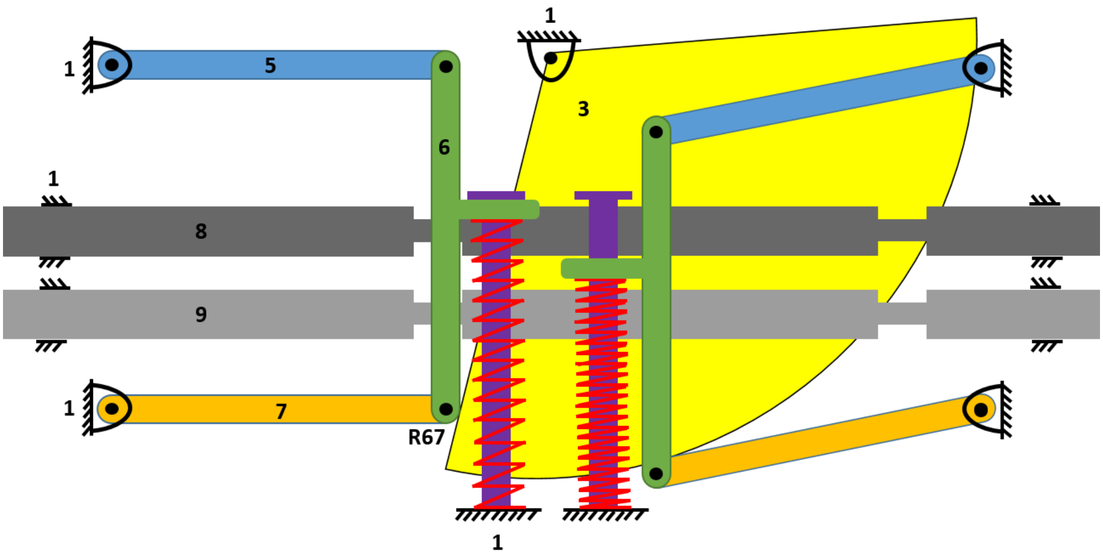
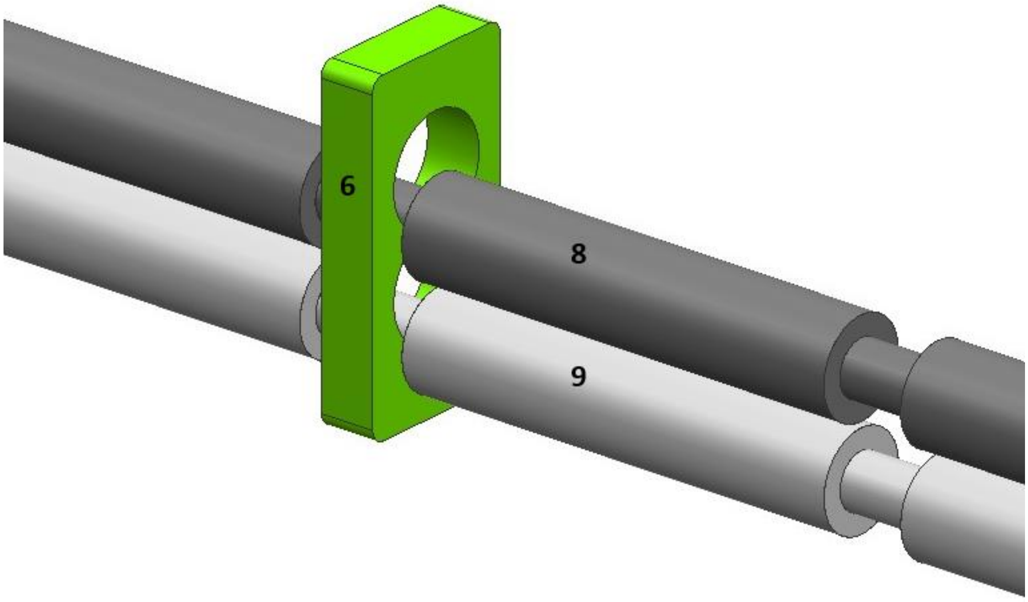


Figure 52 Two detector rods passing through link 6 while the machine is operating

Each detector rod has two narrow sections whose diameters are 20 mm to activate the preloaded locking mechanism. When the machine completes its operation, meaning that the point blades come to one of its end positions, the contact between the rotating disc and revolute joint R67 is removed. At the same time the narrow sections of the detector rods align with the link 6. Hereby, the four-bar locking mechanism under the preload of compressed spring is activated. Figure 53 shows the locked position of the mechanism at the one of end positions of the machine.



(a)



(b)

Figure 53 Schematic representation of locked position of the machine (a) and the position of detector rods passing through the link 6 (b)

At the locked position of the machine shown in Figure 53, the motion of the point blades connected to detector rods are restricted by the link 6 and this position of the link 6 is conserved by the spring which is in compression even at that position. At the same time the rotating disc rests against the bushing placed at the extension of revolute joint R67. In this manner the motion of the rotating disc, indeed the motion of the driving rod, is also restricted.

The distance between the narrow sections on the detector rods need to be adjusted depending on the throwing distance of the machine. When the stroke is adjusted, these distances are also required to be adjusted. The detector rods can be adjusted in steps of 5 mm. There are 5 rings having different lengths of 5, 10, 20, 40 and 60 mm. It is possible to adjust the distance between the narrow sections by using different combinations of these rings. These rings can be installed between the parts having narrow sections or at the end of the rod. To illustrate, Figure 54 presents the pre-assembled combination of a detector rod such that 5 mm, 10 mm and 60 mm rings are installed between the notched parts and the remaining rings are installed at the back side.

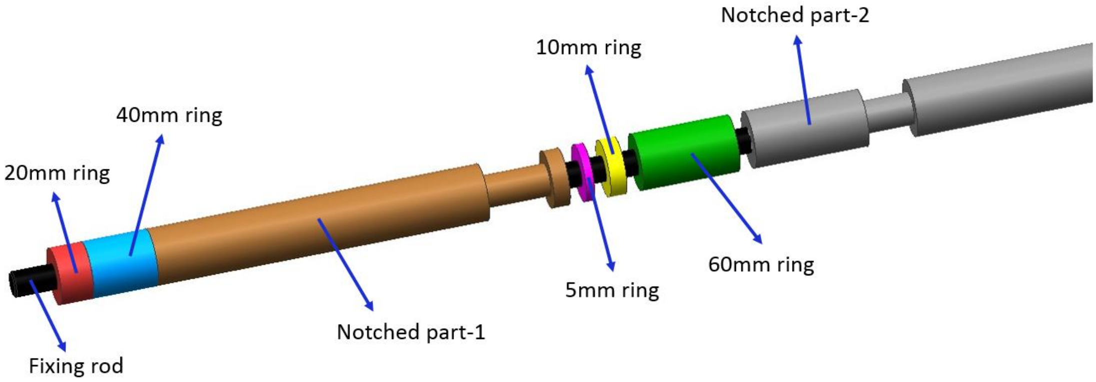


Figure 54 The detector rod adjusted for the 115 mm motion of point blades

Depending on the required motion of the point blades, suitable rings are chosen and installed between the notched parts. Fixing rod is screwed into the notched part-2 to complete the detector rod assembly. The "control distance" shown in Figure 55 corresponds to a specific motion of point blades. If none of the adjustment rings are used between the notched parts, this corresponds to the point blade motion of 40 mm. If the rings having lengths of 5 mm, 10 mm and 60 mm as shown in Figure 54 are used between the notched parts, this means that the detector rod is adjusted for the point blade motion of 115 mm.

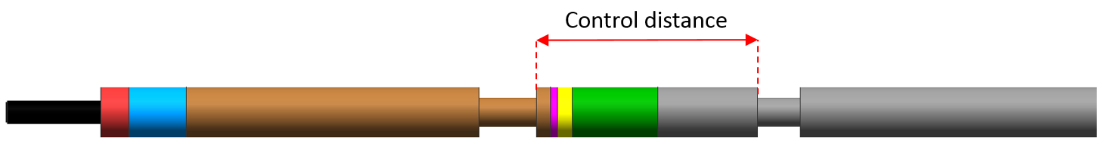


Figure 55 The control distance on the detector rod for the adjustment of different point blade motions

Table 13 presents the rings that must be selected for the required motion of point blades and shows the corresponding control distances.

Table 13 Required rings for the need of point blade motion

Point blade motion (mm)	Rings to be installed between the notched parts	Control distance (mm)
40	-	80
45	5 mm ring	85
50	10 mm ring	90
55	5 mm ring, 10 mm ring	95
60	20 mm ring	100
65	5 mm ring, 20 mm ring	105
70	10 mm ring, 20 mm ring	110
75	5 mm ring, 10 mm ring, 20 mm ring	115
80	40 mm ring	120
85	5 mm ring, 40 mm ring	125
90	10 mm ring, 40 mm ring	130
95	5 mm ring, 10 mm ring, 40 mm ring	135
100	60 mm ring	140
105	5 mm ring, 60 mm ring	145
110	10 mm ring, 60 mm ring	150
115	5 mm ring, 10 mm ring, 60 mm ring	155

120	20 mm ring, 60 mm ring	160
125	5 mm ring, 20 mm ring, 60 mm ring	165
130	10 mm ring, 20 mm ring, 60 mm ring	170
135	5 mm ring, 10 mm ring, 20 mm ring, 60 mm ring	175
140	40 mm ring, 60 mm ring	180
145	5 mm ring, 40 mm ring, 60 mm ring	185
150	10 mm ring, 40 mm ring, 60 mm ring	190
155	5 mm ring, 10 mm ring, 40 mm ring, 60 mm ring	195
160	20 mm ring, 40 mm ring, 60 mm ring	200
165	5 mm ring, 20 mm ring, 40 mm ring, 60 mm ring	205
170	10 mm ring, 20 mm ring, 40 mm ring, 60 mm	210
175	5 mm ring, 10 mm ring, 20 mm ring, 40 mm ring, 60 mm ring	215

When it is needed to change the position of the point, the point machine is operated towards the opposite side. In order to unlock the locking four-bar mechanism, an unlocking disc rotating around the same center with the rotating disc is used. When the hydraulic cylinders are operated in reverse direction, the unlocking disc is first rotated to push down the link 6 by the help of its inclined edge. The unlocking disc at the locked position of the machine is shown as the black part in Figure 56.

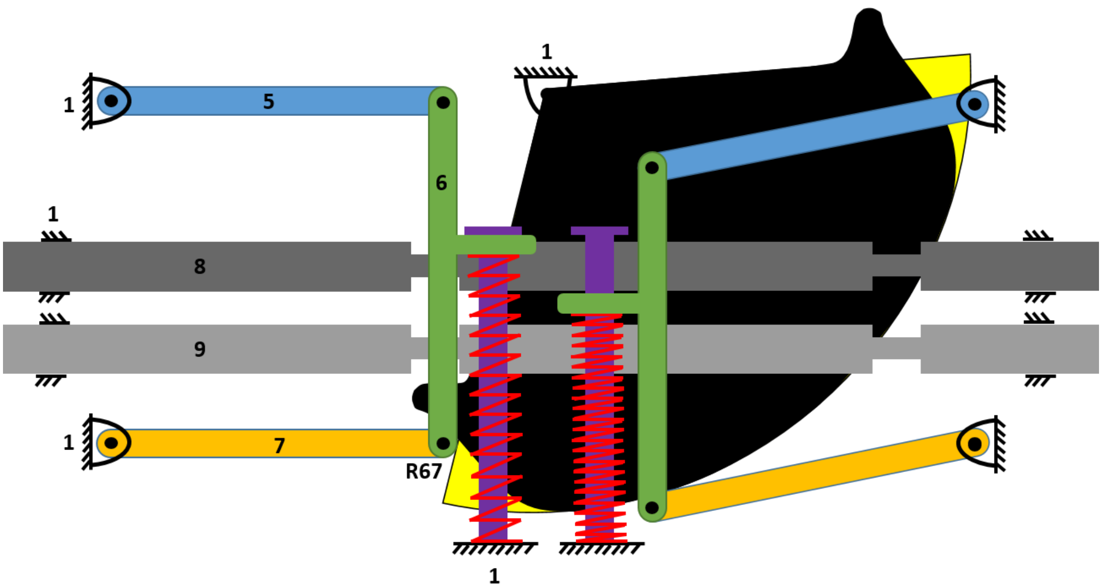


Figure 56 Unlocking and rotating discs at the locked position of the machine

When it is forced to rotate by the hydraulic cylinders, the inclined edge slides on the bushing at the revolute joint R67 and it pushes down the link 6 by compressing the spring. When it comes to end of the inclined surface of the unlocking disc, the locking four-bar mechanism is completely pushed down and the machine is unlocked. Figure 57 shows the time just the machine is unlocked. After that time the unlocking disc rotates together with the rotating disc, hence the driving rod and the detector rods move towards the opposite side.

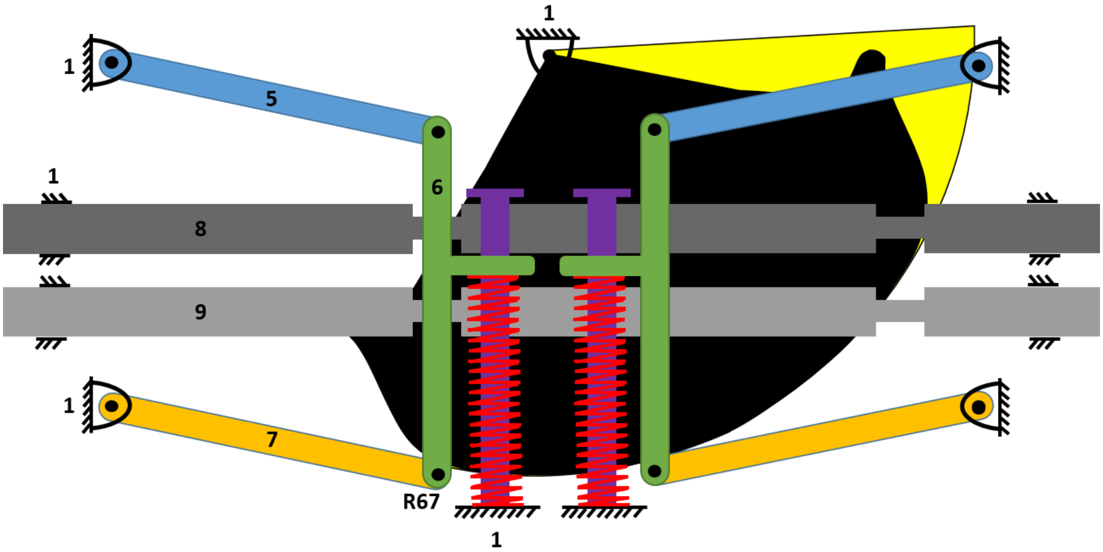
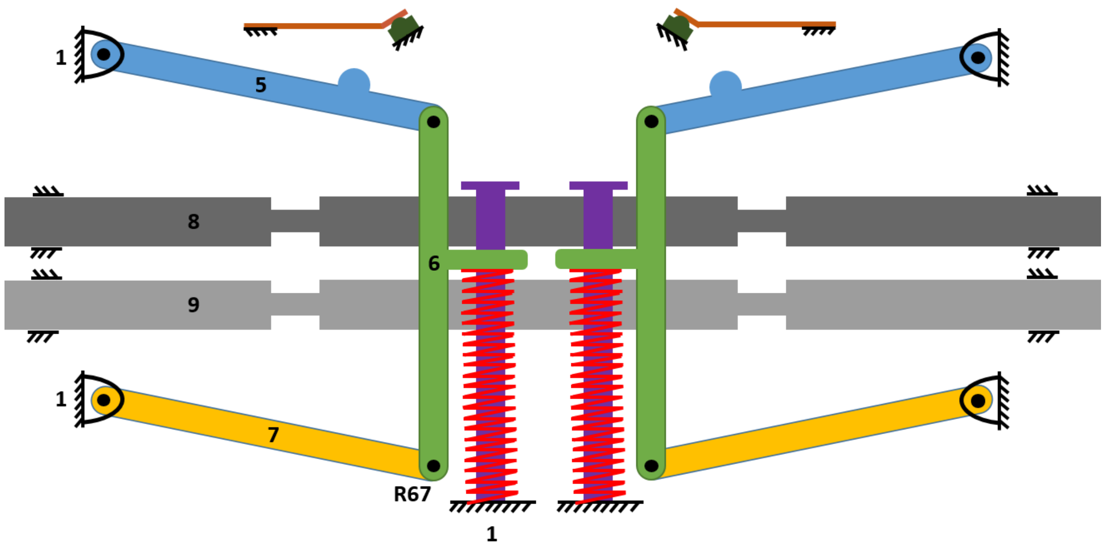


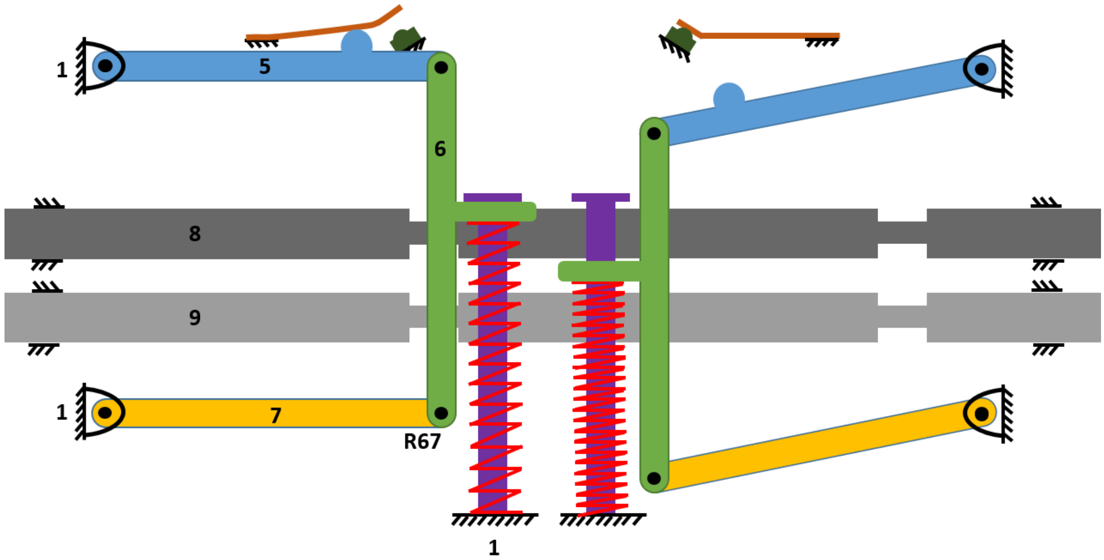
Figure 57 Unlocking and rotating discs at the just unlocked position of the machine

Normally, the rotating disc and the unlocking disc rotates around the same center together however there is a small backlash of about 7 degrees between them. This provides the unlocking disc to rotate about 7 degrees independent from the rotating disc to unlock the mechanism while the rotating disc stands as it is at that small time interval. When the mechanism is unlocked, then they rotate together. This guarantees that the motion of the driving rod is restricted while the mechanism is unlocking.

There are two electrical contact switches installed in the casing near the locking mechanism. These switches are used to inform the control center whether the machine is locked or unlocked. The contact switches are normally closed while the machine is in operation. When it comes to one of its end positions and locked by the four-bar mechanism, the upper arm described by link 5 pushes up the switch and the contact is broken. As a result of this, a signal is sent to the control center stating that the machine is locked. Figure 58 shows the closed and open positions of one of the contact switches depending on locked or unlocked position of the machine.



(a)

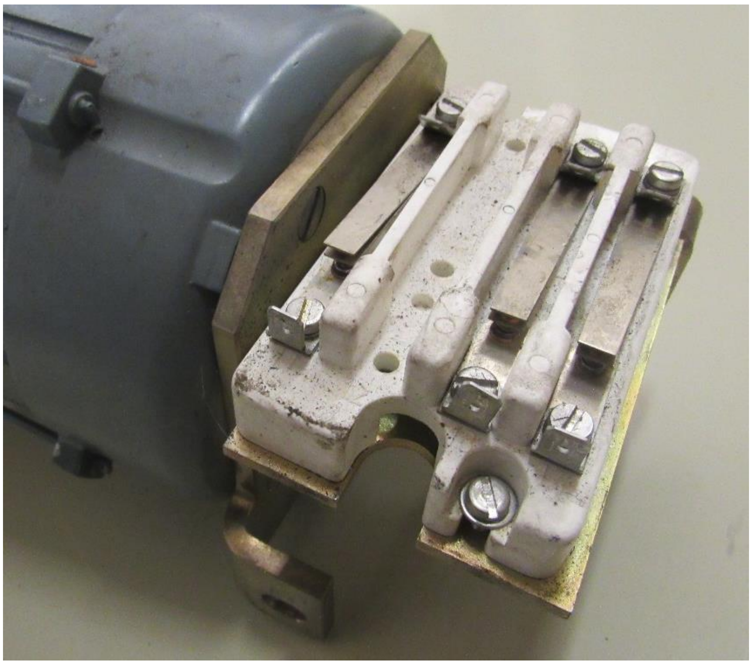


(b)

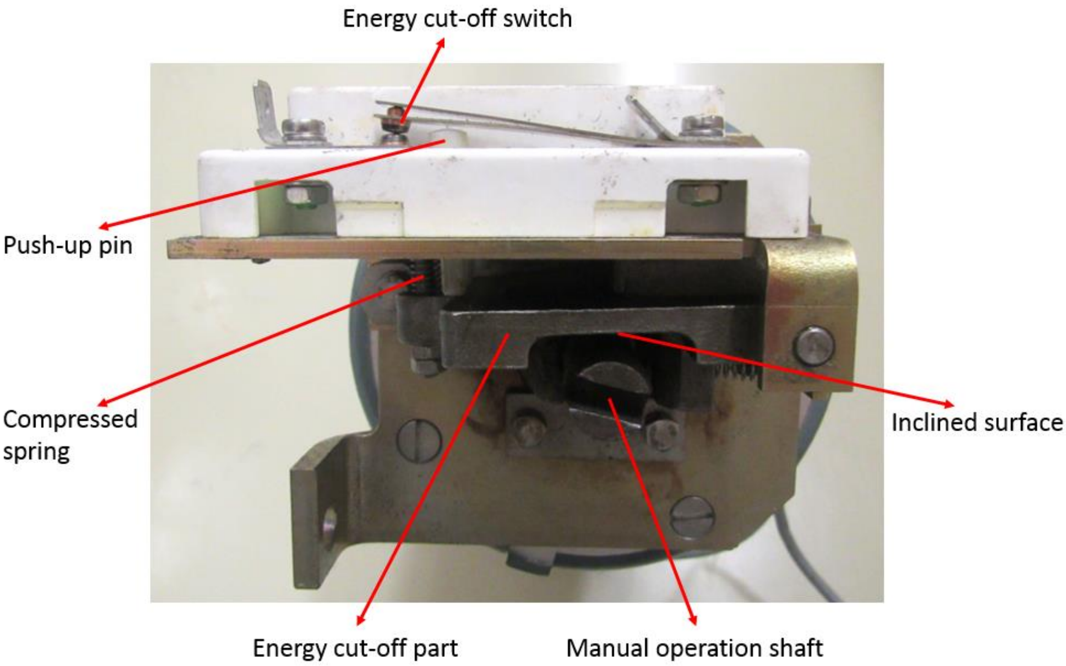
Figure 58 Closed (a) and open (b) positions of the contact switches

There are also three similar contact switches mounted on the electric motor to cut off the supply energy in the case of manual operation of the machine by using a handle. When the machine is needed to operate manually in the case of a fault or for other reasons, the electric motor is driven by rotating its shaft at the back side with the help of a crank. In that case, the supply energy is cut off in order to operate the machine safely. Figure 59 presents the photograph of energy cut-off switches and the manual operation shaft of the motor.

There is no kind of protocol to check the contact problems of these switches caused by oxidation, wire break or arching. Normally a governing signal is generated to inform the control center when the throwing of the machine is completed. If the governing signal is not received although the operation command is sent to the point machine, this is an indicator for the dispatcher to understand that there is a problem about the operation. The problem can be related with the electric motor, locking mechanism, contact switches or any other component inside the machine. This requires in-situ examination on the point machine to understand the reason of fault.



(a)



(b)

Figure 59 Three energy cut-off switches (a) and energy cut-off mechanism (b)

Its mission is similar to link 5 of the locking four-bar mechanism. It is mounted on a fixed part on the motor with a revolute joint and the other end of it is under compression of a linear spring. While the manual handle is being inserted to the shaft of the motor, the handle is touching the inclined surface of the energy cut off part and it is forced to compress the spring by rotating it upwards. When the insertion of manual handle to the motor shaft is completed, the energy cut-off part pushes up the three switches to open them. In this way, the supply energy is cut off and the manual operation of the machine is secured.

3.2 INVESTIGATIONS ON POINT MACHINE B

The point machine B is an electro-mechanical point machine containing an electric motor, gearbox, driving mechanism, locking mechanism, terminal block and contacts. All these components except the electric motor are mounted in a cast steel casing. The electric motor has its own molded steel casing and this circular casing is screwed on the side of the main body of the machine. Main casing is covered with a hot dip galvanized steel plate. Moreover there is a rectangular bar to drive the point blades and there are two additional rectangular bars having relatively smaller cross sections to inspect the correct positions of the point blades respectively. Figure 60 shows the general view of point machine B. Extension part that is seen near the electric motor casing in Figure 60 is used to enclose the extensions of the driving and control rods when the point blades are pulled towards the point machine.

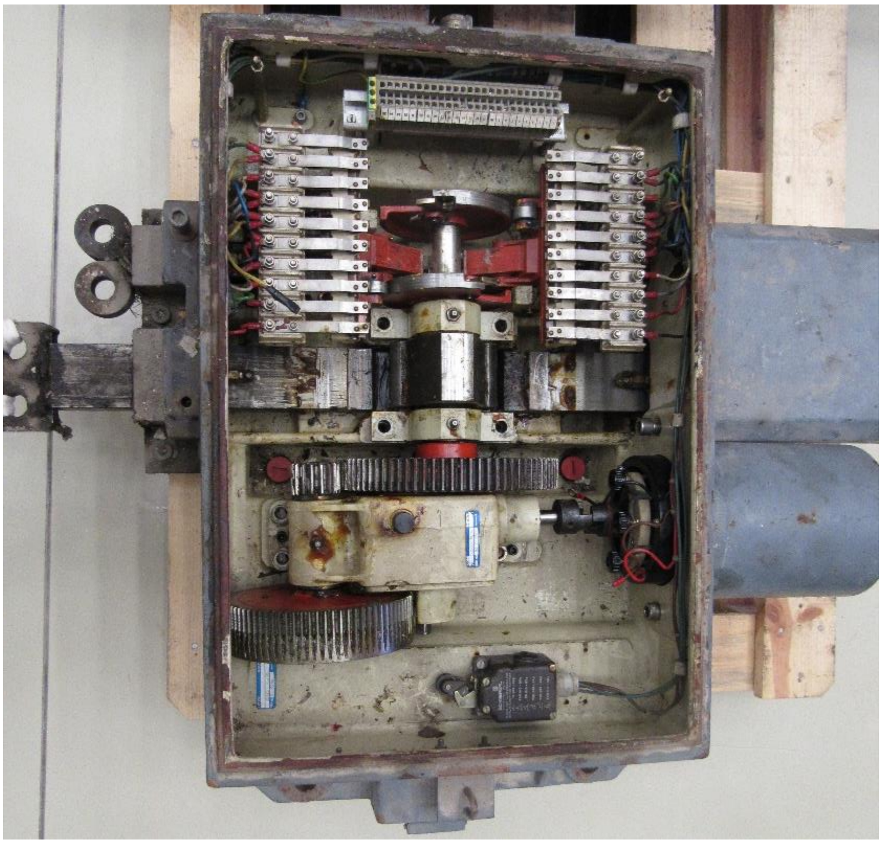


Figure 60 Photograph of inside view of point machine B

The electric motor is enclosed by a circular molded steel casing and it is installed from the side of the main casing horizontally. A sealant material is used on the mating surfaces of these enclosures to prevent leakage. Only a small part of the motor from the front side falls within the main body of the machine. The motor is operated with the voltage of 110 V DC and the maximum current drawn by the motor is 6.2 A under this voltage.

A gearbox is installed at the motor shaft and it changes the direction of shaft motion by 90 degrees. The electric motor is connected to this gearbox with a flexible coupling. In this manner shaft motion of the motor is transferred to the gearbox by compensating axial and angular misalignments. The gearbox ratio is found to be 26. There is a pinion gear at the output shaft of the gearbox and the number of tooth of this pinion is 16.

Driving mechanism of the machine has been analyzed and a representative kinematic model is obtained as shown in Figure 61. A mating gear is mounted next to the gearbox output pinion and these two forms a spur gear mate. The mating gear has 85 tooth. There is a pinion gear placed on top of the driving rod and it is installed on the same shaft with the mating gear. The driving bar and the driving pinion forms a rack and pinion gear mate.

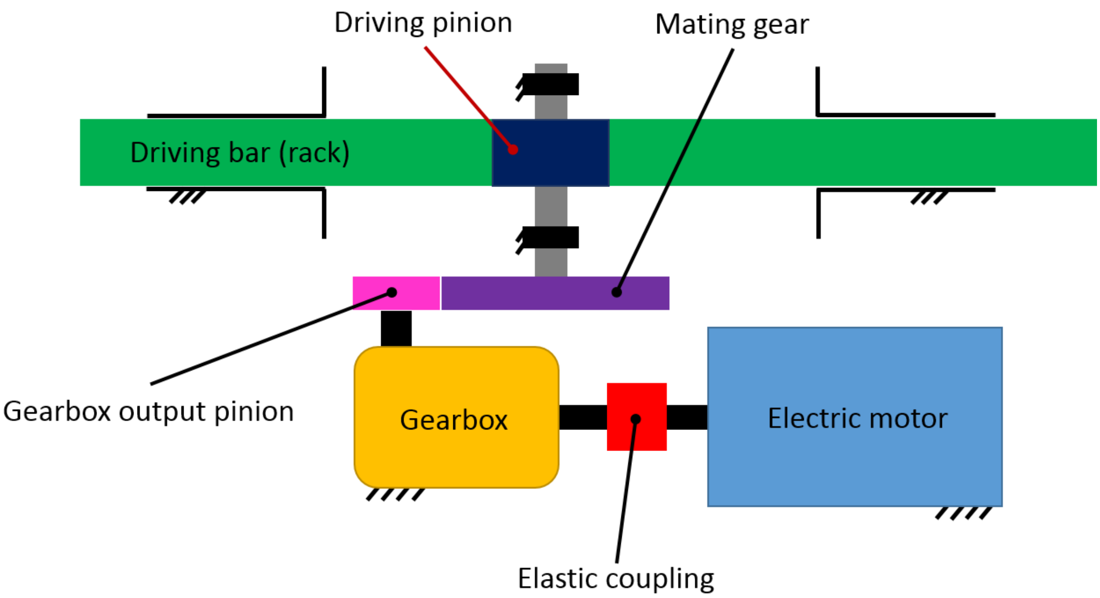


Figure 61 Representative schematic model of driving mechanism from top view

The mechanical parts of the driving mechanism are numbered and these numbers represent the links of the mechanism one by one. The link numbers are shown in Figure 62.

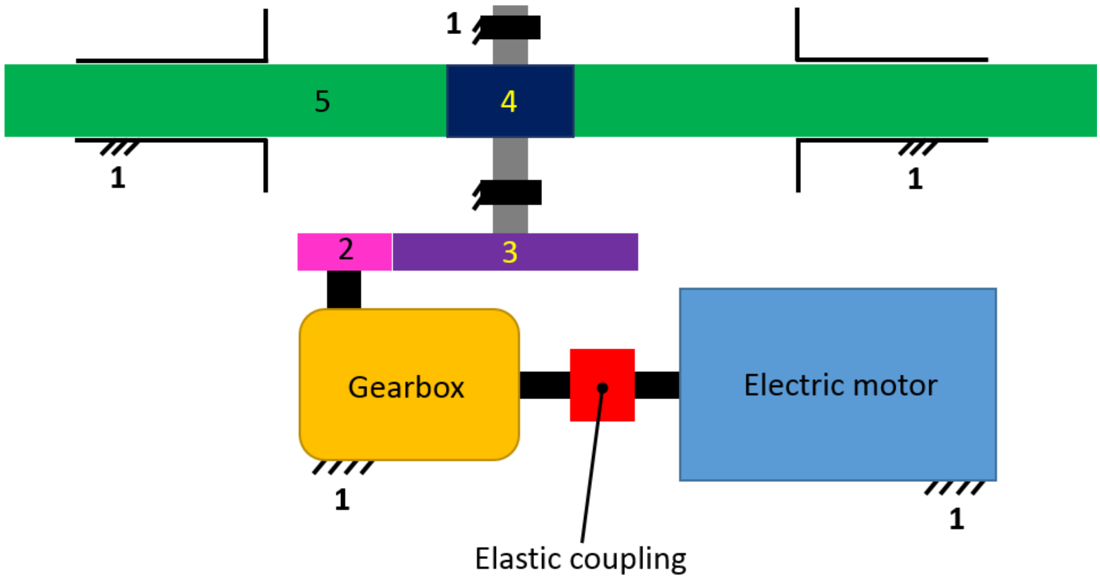


Figure 62 Representative schematic model showing the links of driving mechanism

The link number 1 shown in Figure 62 represents the ground, namely molded casing and other parts which are fixed on it. The link shown by 2 represents the pinion gear installed at the output shaft of the gearbox. The link number 3 shows the mating gear of the link 2. The driving pinion placed on the same shaft with the link 3 is described as link number 4. Finally the link 5 shows the driving bar itself.

In Figure 63, some of the known and measured parameters of the members of driving mechanism are shown. Moreover, efficiencies for some parts of the machine are assumed. First of all, operational voltage and the current drawn by the motor is provided by the manufacturer. The motor draws maximum 6.2 A at 110 V. This means that the motor power can rise up to 682 W. The efficiency of the electric motor is assumed as 85 percent since the typical efficiency values of the motors which have nearly these power capacities are between 0.75 and 0.95 [26]. Therefore the efficiency of this electric motor is assumed as 0.85. The gearbox is dismounted from the machine and the ratio of angular velocities between input and output shafts of the gearbox is found as 26. This indicates that the output shaft of the gearbox rotates 26 times slower than the input shaft. Heat is generated due to the friction inside the gearbox and this results in power loss in the gearbox. The efficiency of the gearbox is assumed as 0.94 by considering the reduction ratio of the gearbox [27]. The gearbox output pinion shown as link 2 has 16 tooth. The tooth number of its mating gear indicated by link 3 is counted as 85. The efficiency of spur gear mate formed by link 2 and link 3 is predicted to be higher than the efficiency of gearbox [27]. The efficiency value of 98 percent is assumed for this spur gear mate [28]. Link 4 namely the driving pinion is also analyzed. The module of the gear is measured as 8 mm and the pitch diameter is measured as 96 mm. Finally, it is known that the throwing stroke of the machine is 160 mm and the switching is performed in 4 seconds. This basically describes the motion of the driving bar indicated as link 5. The efficiency for the rack and pinion gear mate formed by link 4 and link 5 is also assumed as 0.98 similar to spur gear mate.

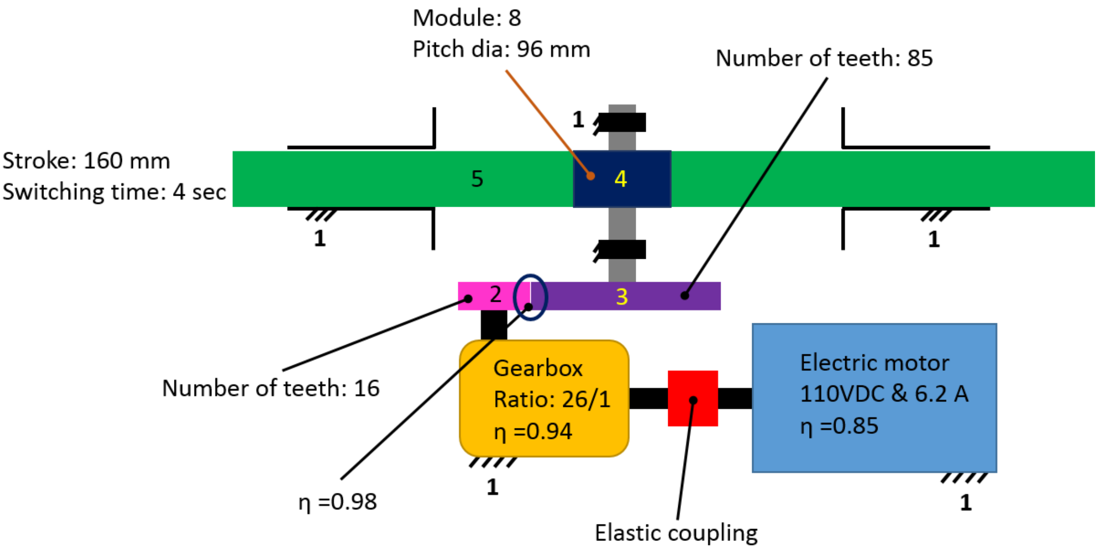


Figure 63 Known and measured parameters of the driving mechanism

Before going into details of analysis of the driving mechanism, free body diagrams of the link 4 and link 5 are drawn and the required dimensions are measured on the machine. These free body diagrams will help to do force analysis and also to transfer the motion parameters to other components of the machine. Figure 64 presents the driving bar and its pinion gear mate from the front side.

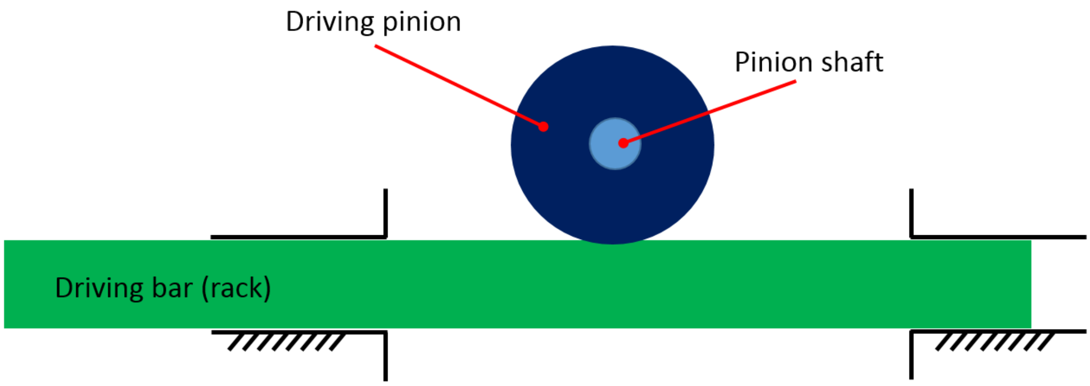


Figure 64 Rack and pinion gear mate in front view

Figure 65 shows the free body diagram of link 4 representing the driving pinion. Pitch diameter of the gear is measured as 96 mm. T4 represents the torque applied on the shaft that the gear is installed on it and w4 shows the rotational speed of the driving pinion. F54 indicates the reaction force of link 5 on the contact point. This force has an inclination due to the gear profile and it can be split into its radial and tangential components. F54_t shows the tangential component of the force F54 while F54_r is showing the radial one. The pressure angle Φ is shown between the force F54 and its tangential component F54_t. Its numerical value is taken as 20 degrees for a standard gear profile in this analysis. The shaft that the driving pinion is mounted on is described by the letter a. The force created on this shaft is shown as Fa4 and it also has the radial and tangential components similar to F54. Radial component of Fa4 is represented as Fa4_r and the tangential component is described as Fa4_t.

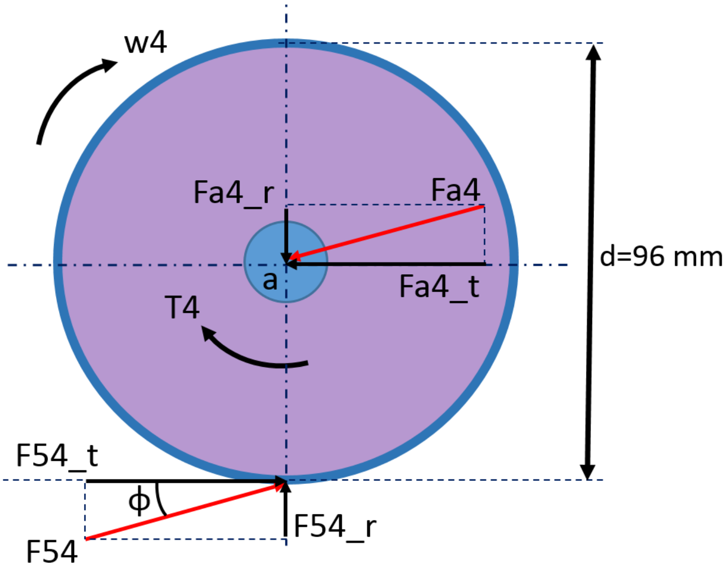


Figure 65 Free body diagram of link 4

Although the free body diagram of the link 4 is drawn as a full circle, almost one third of it is formed as a gear. The actual shape of it looks like the sketch shown in Figure 66.

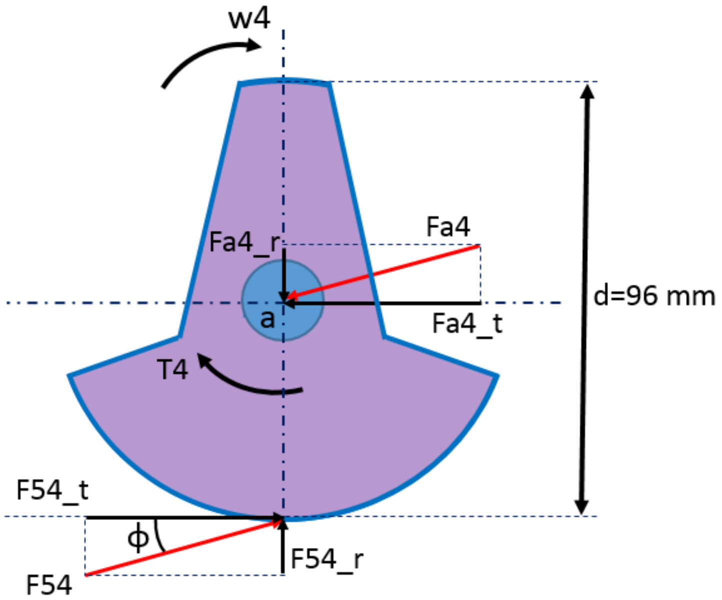


Figure 66 Free body diagram of actual shape of link 4

Figure 67 presents the free body diagram of link 5 representing the driving bar of the machine. The height of the driving bar is shown by d1 and measured as 50 mm. Link 5 moves linearly into two slides that are shown by letters b and c in Figure 67. The distance between these slides are measured as d4=430 mm and the link 4 contacts with the link 5 at the middle of these slides. The contact point of the link 4 is approximately 10 mm below the upper surface of the link 5 due to the gear profile and this distance is described as d2. The force applied by the link 4 on the link 5 is indicated as F45 and it has a same angle Φ like on the link 4. The components of this force along the motion direction and perpendicular to motion direction are shown as F45_t and F45_r, respectively. Reaction force of point blades on the driving bar is represented as F_o. These forces create a moment on the link 5. This moment and radial component of F45 are balanced with the reaction forces created by slides b and c. Reaction forces are placed at the reaction points and shown as Fy15b and Fy15c at the slides b and c, respectively.

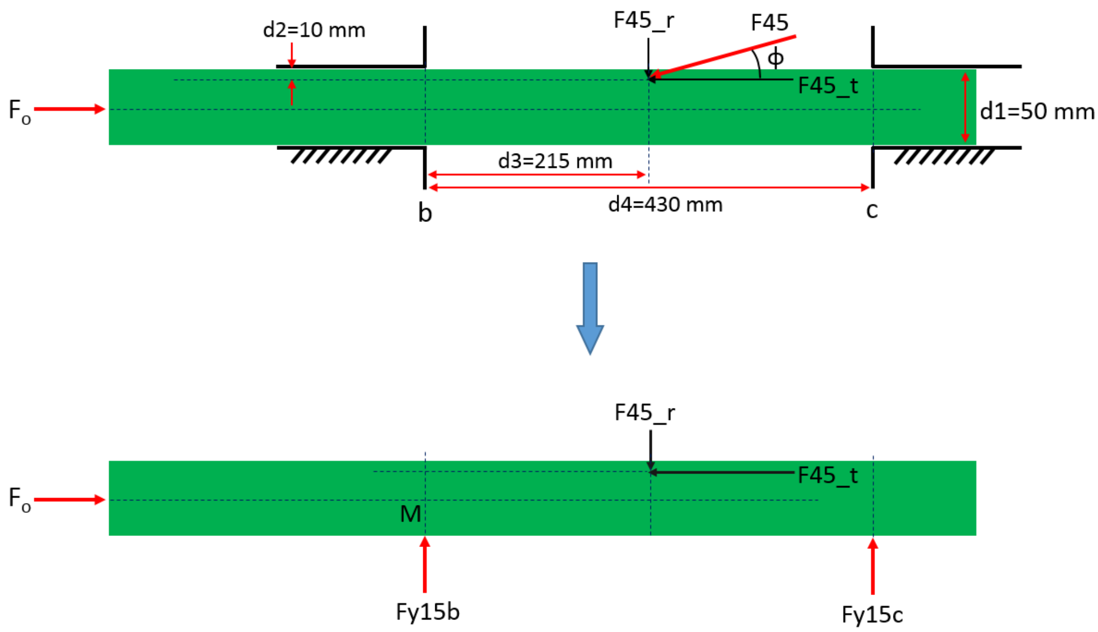


Figure 67 Free body diagram of link 5

In order to start the position and force analyzes of the driving mechanism, it is required to know the rotational speed and the torque of the motor shaft. Although the operational voltage and the current drawn by the motor are provided by the manufacturer, neither rotational speed nor applied torque are provided. However throwing distance and switching time of the machine are the known parameters. Therefore it is possible to come back to the input motion of the electric motor by using the parameters of transmission components between the driving bar and the electric motor.

It is important to decide the motion characteristics of the driving bar. It moves 160 mm in 4 seconds but the velocity profile is not known. It is directly related with the motor characteristics. DC electric motors typically have the power curve presented in Figure 68 [29], [30]. In the first region, the motor power linearly increases with the rotational speed. After a certain speed, the motor provides almost constant power like in the second region. It is assumed that the motor of this point machine operates in the first region closer to the second region since the motor torque is constant at its maximum value in this region. The torque reduces with the increasing rotational speed of the motor after the end of first region. Therefore it is a reasonable approach to have maximum torque with the acceptable power below its maximum.

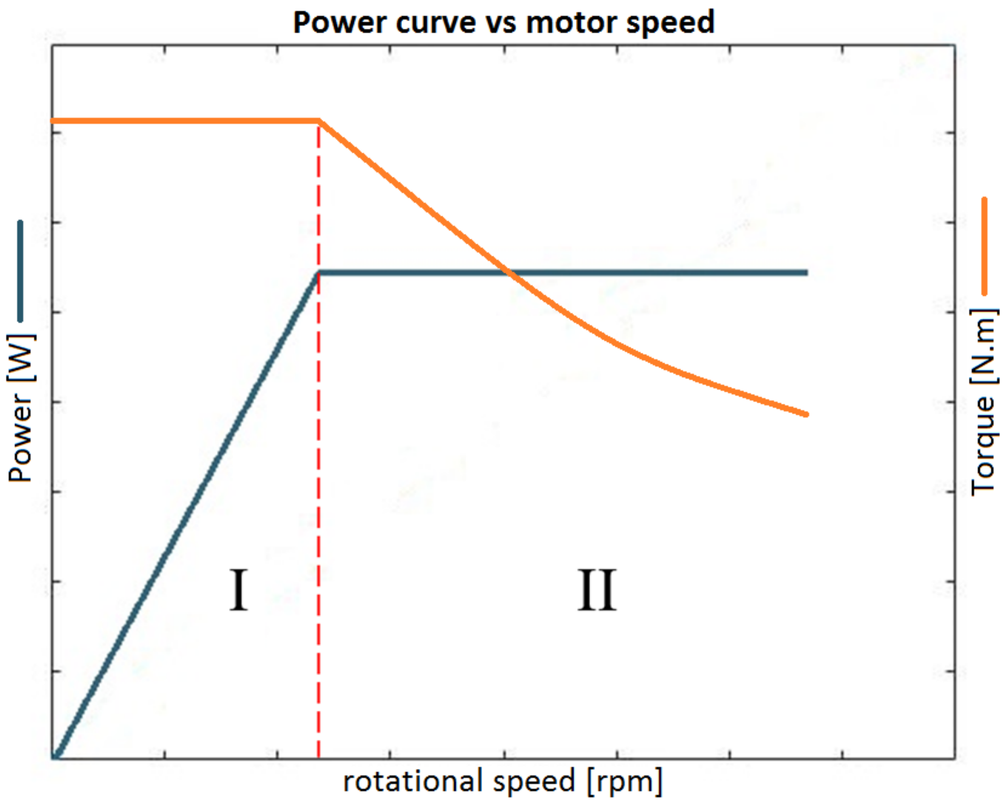


Figure 68 Typical power and torque curve of a DC electric motor

For the driving bar, it is possible to assume a linear velocity profile at the very beginning of the operation and a constant velocity profile during remaining of the operation. The velocity starts from zero at time equals to zero seconds and increases with a constant acceleration until the constant speed operation. Then the driving bar moves with a constant speed till the end of throwing motion. The assumed velocity profile of the driving bar during its throwing motion is presented in Figure 69. Although the real velocity profile can slightly be different from this assumption, it is an adequate approach and easy to solve.

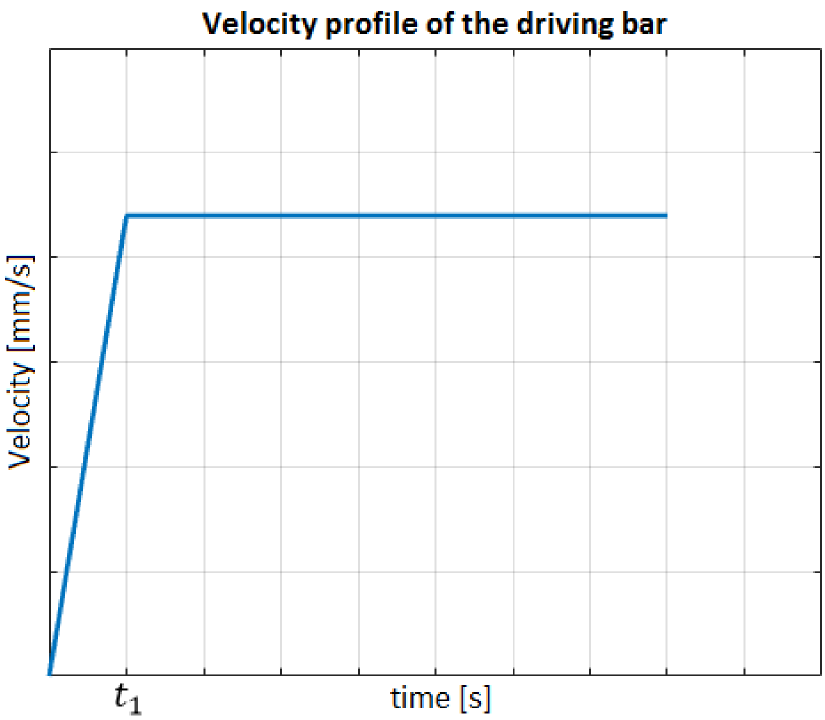


Figure 69 Assumed velocity profile of the driving bar during its throwing motion

The equation of the velocity curve can basically be described as the combination of linear and constant functions:

$$V = a * t; \quad for\ 0 < t \leq t_1$$
$$V = a * t_1; \quad for\ t_1 < t < 4 \tag{3-11}$$

The area under the velocity versus time curve gives the displacement of the driving bar and shall be equal to 160 mm. In order to calculate the area under the curve, it is needed to integrate the equation with respect to time.

$$\int V = \int a * t + \int a * t_1 \tag{3-12}$$

$$\int V = \left.\frac{a * t^2}{2}\right|_0^{t_1} + a * t_1 * t|_{t_1}^4 \tag{3-13}$$

The time t_1 when the velocity of the driving bar stabilizes is assumed to be 0.5 seconds. The numerical value of the area can be calculated by evaluating the equation (3-13) over the switching time.

$$\int_{t=0}^{t=4} V = \frac{a * 0.5^2}{2} + a * 0.5 * (4 - 0.5) = 160 \tag{3-14}$$

By solving the equation (3-14), a can be found as 85.33 mm/s^2. Therefore, rewriting the equation (3-11), velocity profile of the driving bar can be obtained as following:

$$\begin{gathered} V = 85.33 * t; \quad for\ 0 < t \leq 0.5 \\ V = 42.67; \quad for\ 0.5 < t < 4 \end{gathered} \tag{3-15}$$

After finding the equation (3-15), assumed velocity profile of the driving bar can be numerically plotted shown in Figure 70.

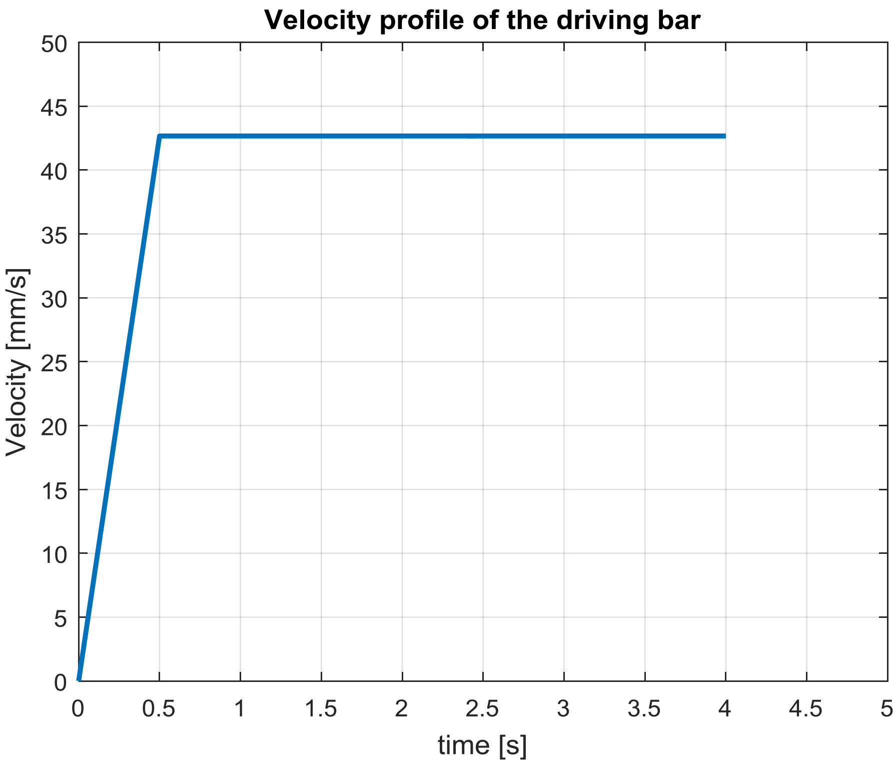


Figure 70 Velocity profile of the driving bar

Rotational speed of the electric motor can be found by knowing the motion characteristics of the driving bar. The method is to come back from the velocity of driving bar to the rotational speed of the electric motor by using the transmission components in between. A Matlab code presented in Appendix C.2 is written to analyze the motion characteristics of the electric motor and the applied forces on the components of the machine. Figure 71 shows the supply power change of the motor with respect to rotational speed of the motor. The power supplied from the motor linearly increases up to 220 W during the operation of the machine.

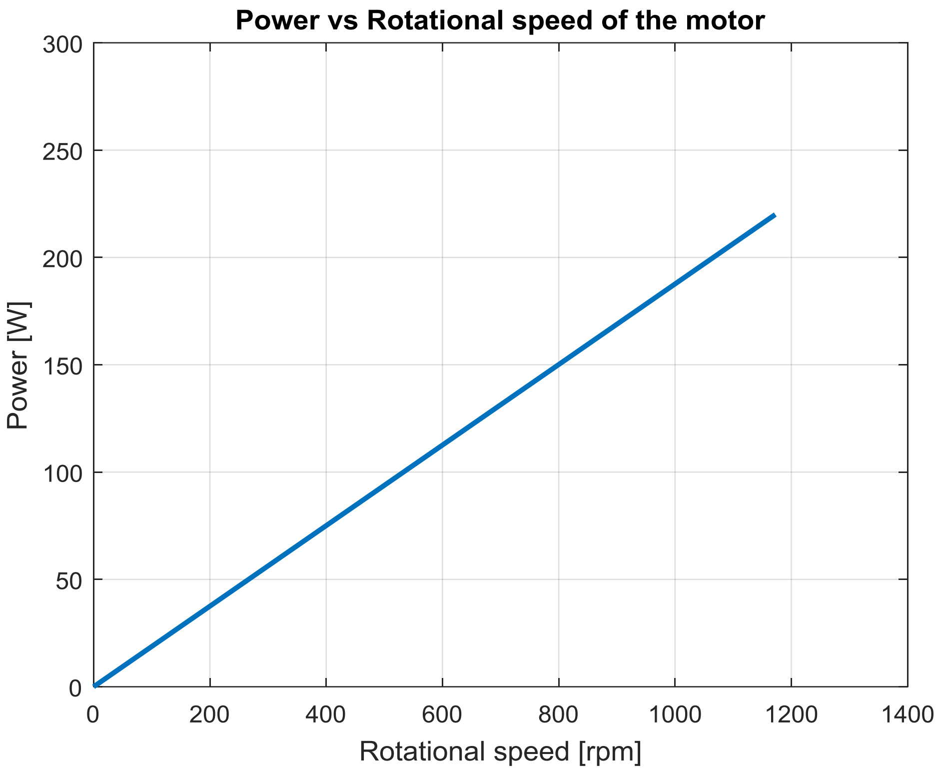


Figure 71 Power curve of the electric motor with respect to rotational speed

The change of the motor speed in the operation time of the machine is presented in Figure 72. Rotational speed of the motor described by “wm” increases with a constant acceleration of 245.3 rad/s^2 up to 1170 rev/min and then is kept as constant at that speed during the throwing motion of the driving bar.

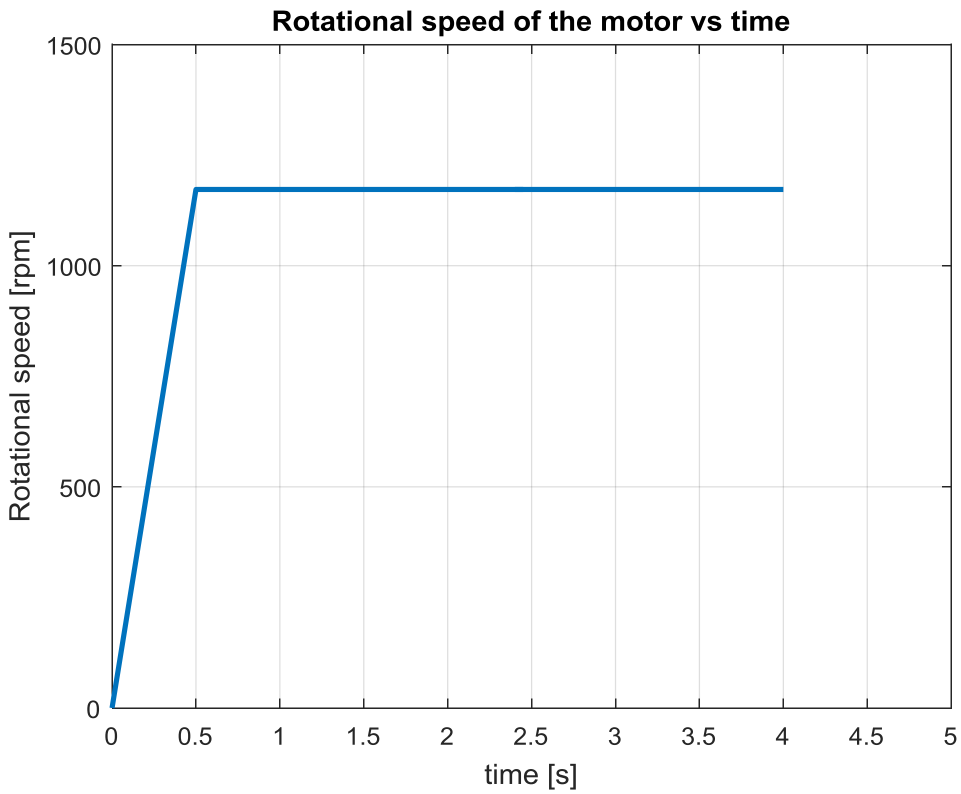


Figure 72 Motor speed during the operation of the machine

The torque applied by the motor indicated by “Tm” can also be calculated by knowing the supply power and the rotational speed. Figure 73 presents the torque curve of the motor in its operational time interval. The motor provides constant torque of 1.52 N.m as expected because the slope of the linearly increasing power curve presented in Figure 71 gives the torque applied by the motor.

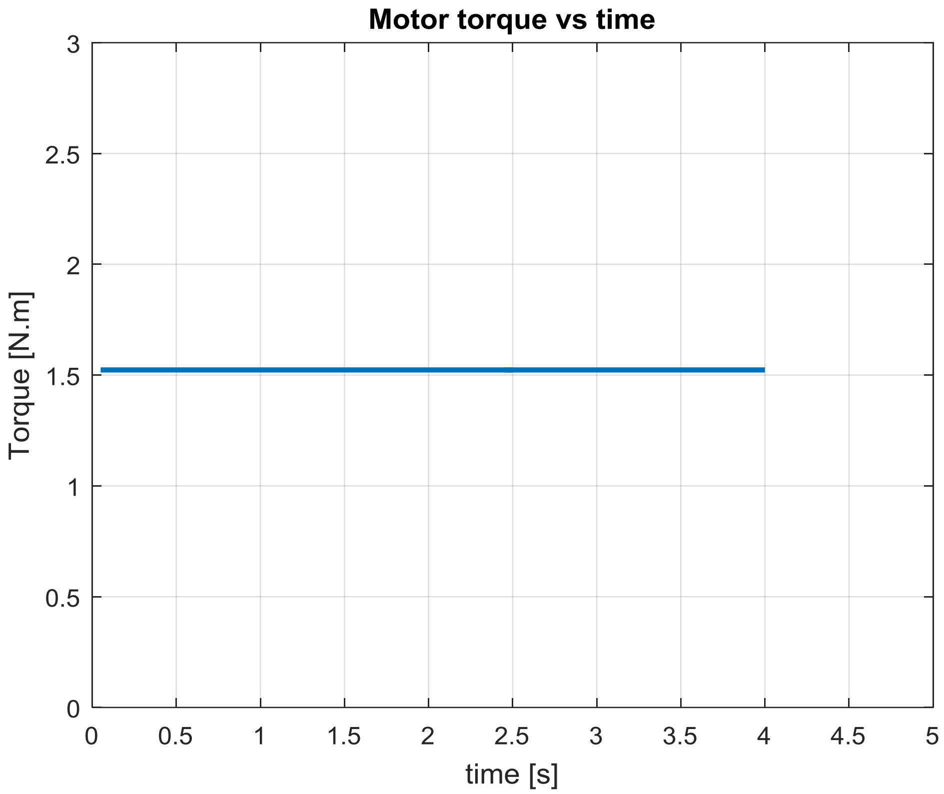


Figure 73 Motor torque during the operation of the machine

The constant torque provided by the electric motor is transferred to the link 4. The torque created on the link 4 is identified as “T4” and it is calculated as 193.8 N.m by the help of Matlab code. Then the applied load on the driving bar along the operation direction “F45_t” is calculated as 4190 N.

Although operational efficiencies of the transmission components like gearbox and gear mates are taken into account while calculating the force that the driving bar applies, the frictional force on the rectangular linear bearings that the driving bar slides in them is not considered. This friction force is measured by using a force measurement device. This measurement is repeated at least ten times in order to be sure that the measurements are consistent. Figure 74 shows a photograph taken during one of this measurements. The frictional force at the linear bearing was measured as 50 N at average while the driving bar is moving. The maximum force is measured as 60 N at average and it is observed at the impending motion of driving bar.

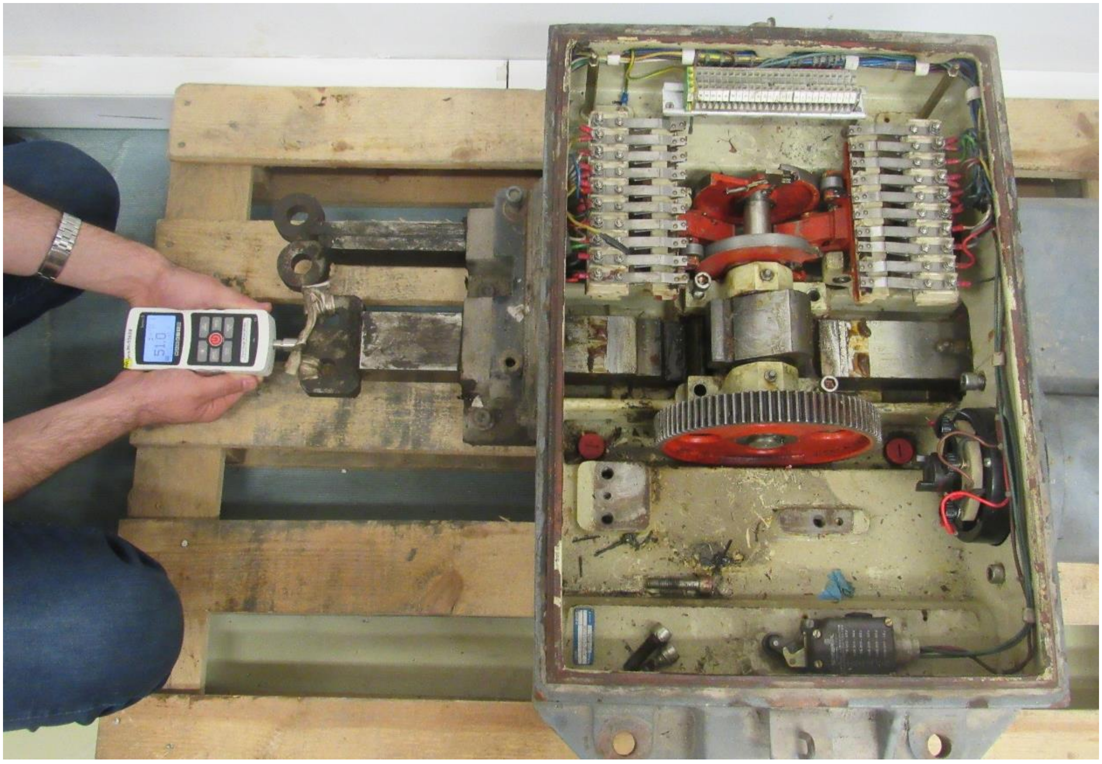


Figure 74 Force measurement at the linear slides

Finally if the frictional force at the slides is excluded from the applied load on the driving bar, the net force applied on the point blades by the driving bar is found as 4140 N. Figure 75 presents the net force that this point machine applies on the point blades. Since the torque produced by the motor is constant during the operation of the machine, the net force applied to throw the point blades is also constant.

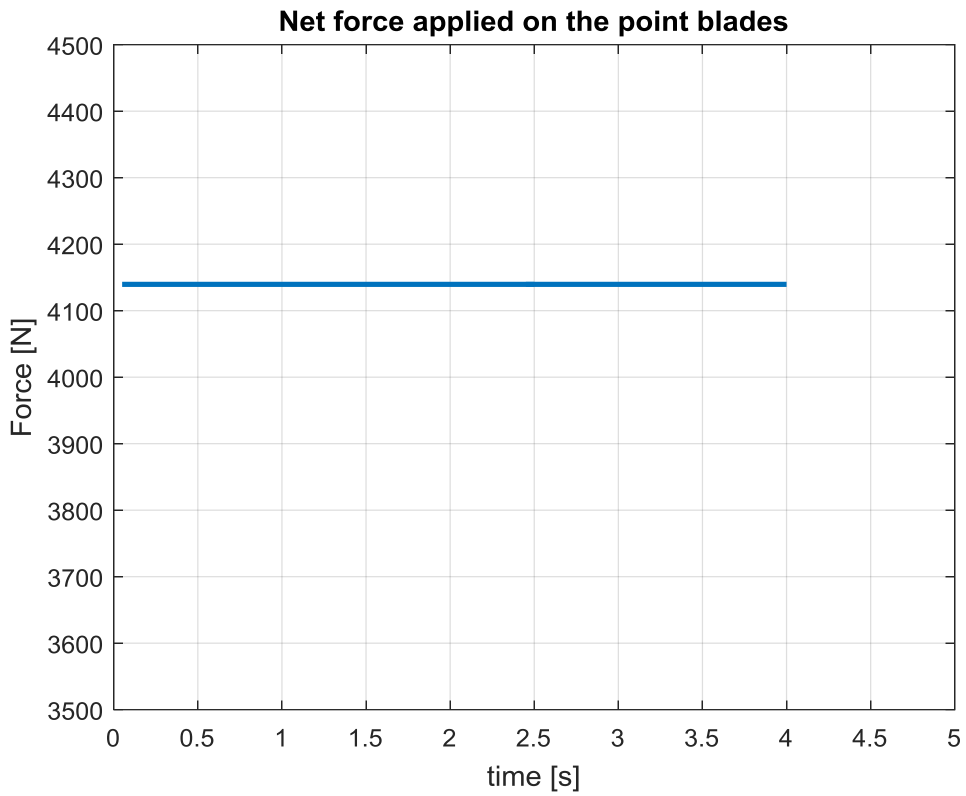


Figure 75 Net force applied on the point blades by the point machine B

As described at the beginning of this chapter, there are two detector bars having rectangular cross sections to check the correct position of the point blades one by one. One of them is mechanically connected to tip of the near point blade and the other one is connected to tip of the distant point blade by the help of mechanical linkages. When the blades of the point come to one of the end positions and the engagement occurs with the stock rail, a locking mechanism is activated automatically at these positions. Indeed the locking mechanism locks the two detector bars which are mechanically connected to point blades. In this way the motion of the point blades is prevented and the point is locked. The reason why there are two detector bars is to control both of the point blades independently. The locking mechanism does not work if one the detector bars, in fact the point blades, is not in the desired position. It works only when both of the point blades are in the desired position.

The second thing keeping the locked position of the machine is the gearbox itself. The use of a worm and wheel gear set in the gearbox provides sufficiently high friction to be self-locking. In such cases, the worm is always the input gear and cannot become an output gear. If the torque is applied to the wheel gear, worm gear cannot be rotated due to friction locking. This can be a desired feature if the existing position is required to be kept like in this point machine. The worm gear in the gearbox is driven by the motor and the wheel gear is intended as the output gear. Therefore a force applied by the point blades on the driving bar cannot rotate the gearbox in reverse direction.

The two detector bars and the main components of the locking mechanism are shown in Figure 76. There are two locking discs installed on the same shaft with the link 3 and link 4. They are in contact with the two rolling discs individually. The rolling discs are mounted on two separate detector arms. These rolling discs can rotate about their own axis freely.

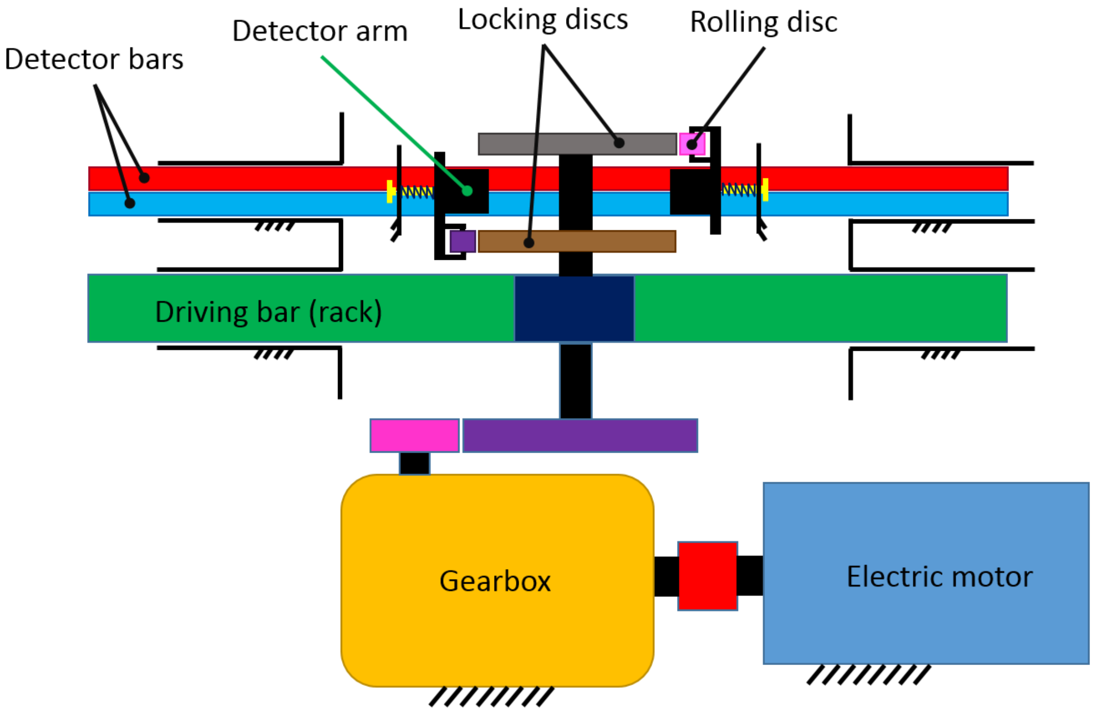


Figure 76 Representative schematic model of locking mechanism together with the driving mechanism from top view

Figure 77 shows the unlocked position of the locking mechanism. Since the two locking discs are mounted on the same shaft, the one that is close to the driving bar is hidden in Figure 77 to see the locking components more clearly. The locking disc shown as link number 7 is continuously in contact with the rolling disc indicated by link number 8 during the throwing motion of the machine. Therefore it pushes the detector arm described by link 9 to the right and compresses the spring placed at the back side of the detector arm while the machine is throwing the point blades. Similarly, the hidden locking disc in front of the link 7 is in contact with the rolling disc and keeps the spring in compression by pushing the detector arm at the left side during the operation of the machine. Since the two detector bars shown as link 6 and its mate behind it are mechanically connected to the tips of the point blades, they slide into the linear bearings at two ends with the motion of point blades.

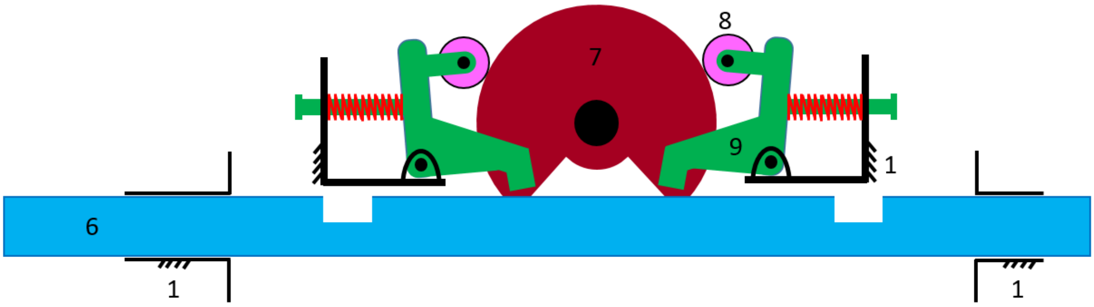


Figure 77 Schematic representation of the locking mechanism in front view

The height and the width of detector bars are 50 and 15 mm, respectively. Each detector bar has two recesses whose heights are 35 mm to activate the preloaded locking mechanism. When the machine completes its operation, meaning that the point blades come to one of its end positions, the radial contact between the locking disc and the rolling disc is removed. At the same time the recessed sections of the detector bars align with the protruding tip of link 9. Hereby, the locking mechanism under the preload of compressed spring is activated. Figure 78 shows the locked position of the mechanism at the one of end positions of the machine.

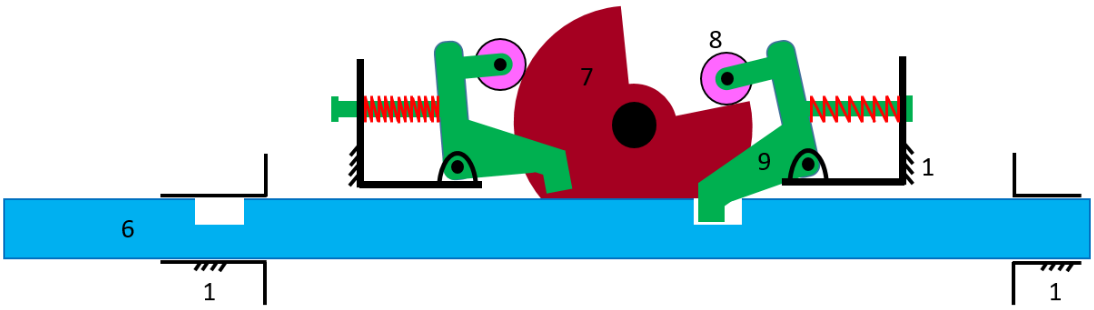


Figure 78 Schematic representation of locked position of the machine

At the locked position of the machine shown in Figure 78, the motion of the point blades connected to detector bars are restricted by the link 9 and this position of the link 9 is preserved by the spring which is in compression even at that position. At the same time the motion of the driving bar is restricted by the gearbox and gear pair up to a certain limit of force.

Basically, when the throwing operation of the machine is finished, the locking mechanism is activated automatically. However, in order to prevent the looseness that can occur between the point blades and the stock rails, an additional part shown as link 10 is used to delay the activation of the locking. Essentially the radial contact between the link 7 and link 8 is removed when the motion of the driving bar is finished but the link 8 begins to touch the link 10 radially just before removing the contact with link 7. From this moment, the driving bar continues pushing or pulling the point blades to the stock rails by forcing the engagement. In this manner, the link 7 rotates about 9 degrees more to remove the radial contact between the link 8 and link 10.

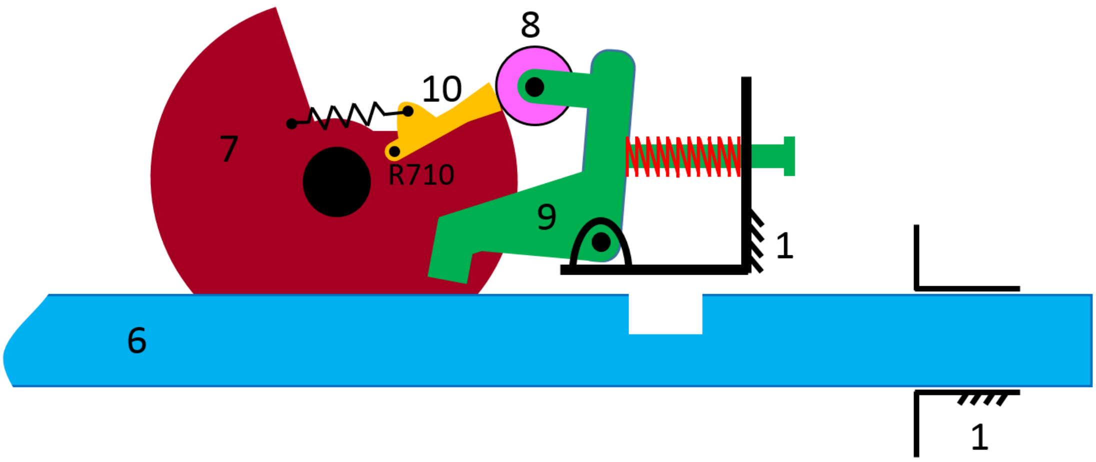


Figure 79 Schematic representation of locking delay

Finally the link 10 rotates about the revolute joint indicated by R710 by stretching the spring installed between the link 7 and link 10. Hereby, the machine provides and maintains a tight engagement of the point blades at the end positions. Figure 80 presents the locked position of the machine at one of the end positions with a tight engagement of the rails.

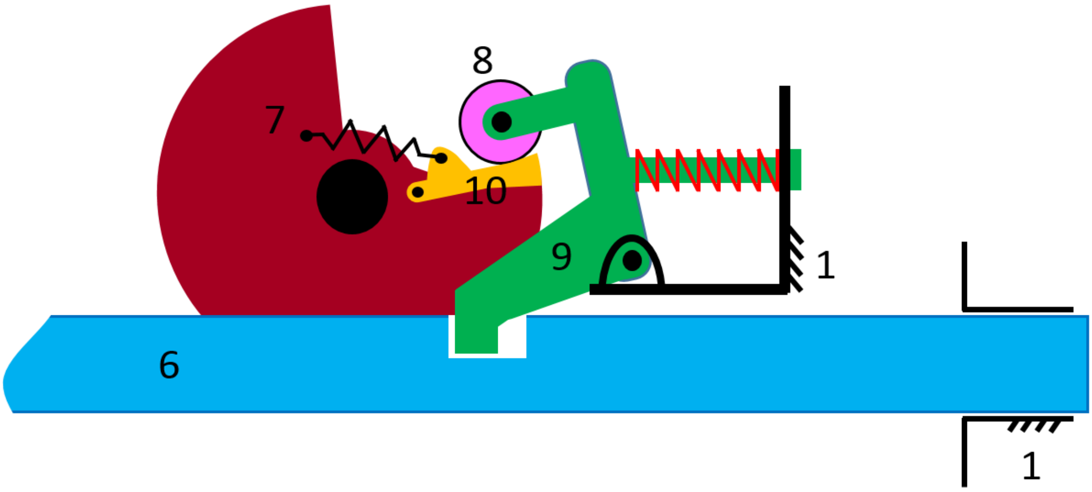
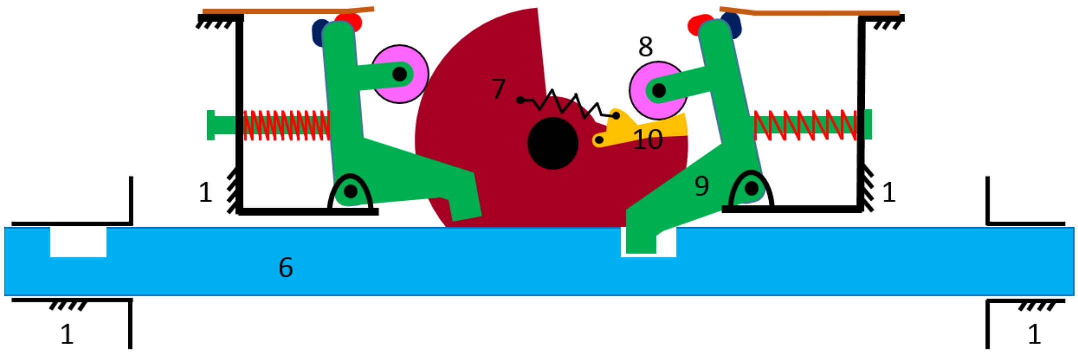


Figure 80 Schematic representation of locked position with a tight engagement

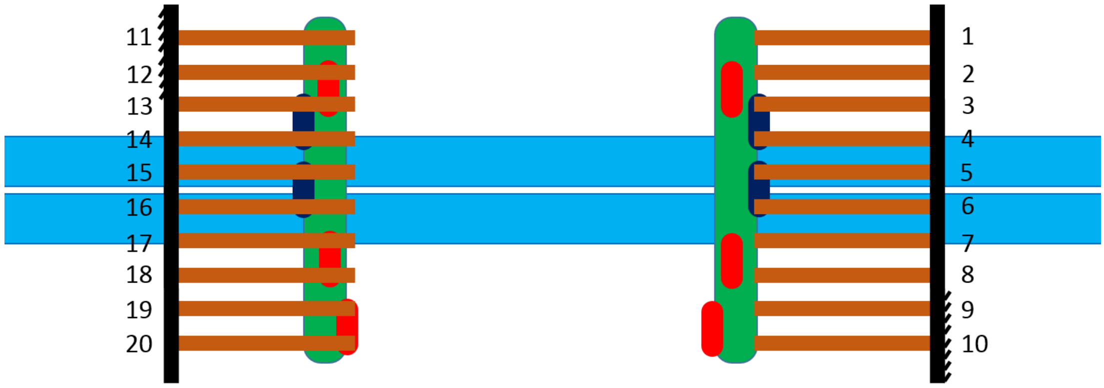
Since the distance between the recessed sections on the detector bars is constant and the rotation of the driving pinion shown as link 4 has a certain limit, the stroke of the machine could not be adjusted. Therefore this point machine can only be used on the points having an arrangement clearance of 160 mm.

When it is needed to change the position of the point, the point machine is operated towards the opposite side. In order to unlock the locking mechanism, the electric motor is driven in the reverse direction and thus the shaft rotates in the other direction. Rotation of the link 7 in the unlocking direction provides the link 9 to get out of recessed section on the detector bars by compressing the spring behind the link 9. After that the point blades are moved to the other end position. When the throwing motion of the blades is finished, the locking mechanism at the opposite side is again activated.

There are twenty electrical contact switches installed on fixed parts in the casing just above the locking mechanism. These switches are essentially used to inform the control center whether the machine is locked or unlocked. Half of them are positioned on the left hand side and the other half are positioned on the left hand side. Figure 81 shows the arrangement of these contact switches.



(a)



(b)

Figure 81 Position of the contact switches from front (a) and top (b) views for one of the locked positions

They function in a meaningful way two by two. If the pair of contact switches touch the same conductor, this means that they close the related circuit and current passes through them for the generation of signal to the control center.

The switches number 1 and 11 shown in Figure 81 are idle and may be used as spare parts in case others are damaged. In the locked position, say in normal position, presented in Figure 81, the switches number 19 and 20 are in short circuit. This means that a signal is generated to decide the rotational direction of the motor. For example, the motor can only be rotated in the reverse direction. The contacts 9 and 10 close the circuit in the reverse position of the point, and thus signal is generated allowing the motor to be rotated in normal direction. If the machine is at an intermediate and unlocked position, the switch pairs 19-20 and 9-10 are both in short circuit. This means that the motor can be rotated in any direction when the machine is in intermediate position.

The switch pairs 17-18 and 12-13 are used for the supply voltage to operate the electric motor. One of these pairs, say switch numbers 17 and 18, completes the circuit for the positive pole of 110 V DC. At the same time, other pair consisting of switch number 12 and 13 is in short circuit for the negative pole of supply voltage. Similarly, the contact switch pairs 7-8 and 2-3 perform the same function when the point is in reverse position.

When the machine is locked in normal position shown in Figure 81, the contact switches 3 and 4 are in touch with the same conductor. Similarly the switches 5 and 6 are closed at the same time. While one of these switch pairs carries the information about the positive pole of 30 V DC for the detection of locked position of the machine, other pair closes the circuit for the negative pole of detection voltage. In a similar way, the contact switch pairs 13-14 and 15-16 perform the same detection function of locking in the reverse position of the point.

Contact problems of the switches caused by oxidation, wire break or arching are not detected by an external protocol. After the throwing of the machine is completed, a governing signal is generated to inform the control center. Although the operation command is sent to the point machine, not receiving of the governing signal by the control center is an indicator of an operational problem for the dispatcher. The reason of the problem can be the electric motor, locking mechanism, contact switches or other components inside the machine. In this case, in-situ examination on the point machine is required to diagnose the fault.

There is also a safety cut out switch mounted in front of the hand crank hole inside the casing to cut off the supply energy. When the machine is operated manually in the case of a fault or for other reasons, the gearbox is driven manually with the help of a hand crank. In that case, the crank hits the switch and breaks electrical connection of the electric motor, so the supply energy is cut off in order to operate the machine safely. Figure 82 presents the photograph of safety cut out switch.

Figure 82 Safety cut out switch for manual operation

3.3 INVESTIGATIONS ON POINT MACHINE C

The point machine C is an electro-hydraulic point machine including a hydraulic power unit, driving mechanism, locking mechanism, detection mechanism and contact switches. All these components are installed in a molded steel casing. Additionally there are two driving rods having circular cross section to move the point blades and two detector rods having circular cross sections to supervise the correct position of the point blades one by one. General inside view of point machine C is shown in Figure 83.

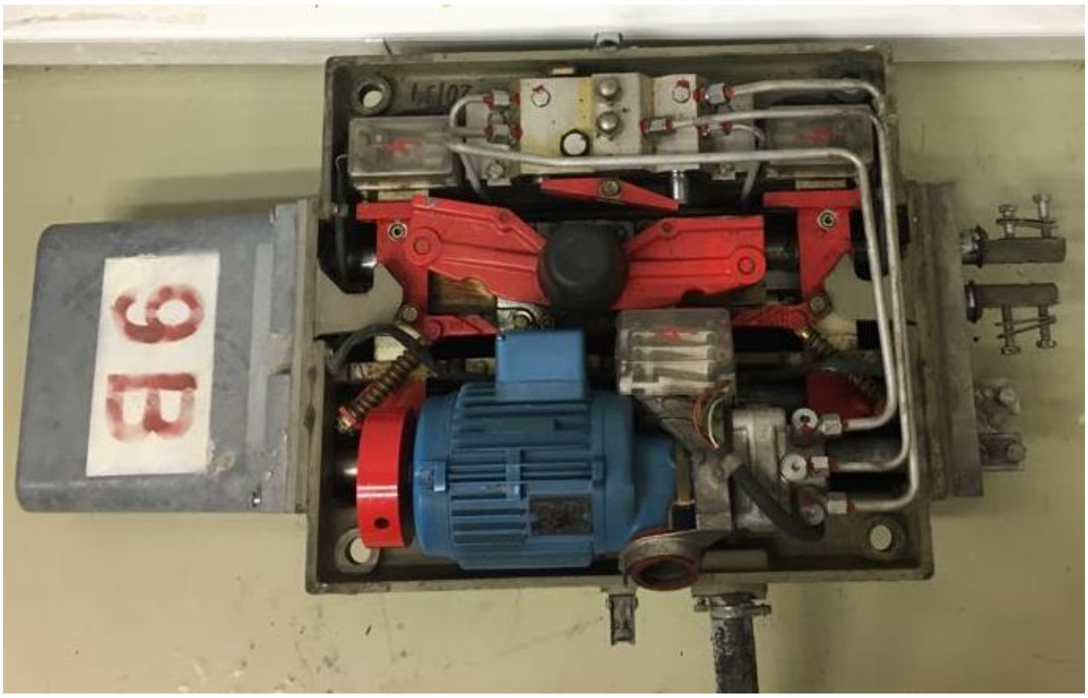


Figure 83 Photograph of inside view of point machine C

The hydraulic power unit contains a mono-phase electric motor having the power of 750 W. The current drawn by the motor is 5.7 A under the potential of 220 V. Rotational speed of the motor is 890 rev/min. It has a dustproof enclosure with the ingress protection rating of IP 54.

The hydraulic unit does not have a compact form. The electric motor and reversible radial piston pump are mounted on one side and a hydraulic block including an oil tank, check valves and adjustable relief valves are positioned on the other side of the casing. There are three aluminum pipes having an external diameter of 10 mm between the pump and hydraulic block to provide oil transfer. The pump is directly mounted on the output shaft of the electric motor with a flexible coupling to generate the pressure. Two hydraulic cylinders are installed at the bottom of the molded steel casing to move the throwing block. These cylinders are fed with the hydraulic fluid through the aluminum pipes having the same external diameters as the others. The radial piston pump pressurized the hydraulic fluid with a flow rate of 1.7 cm^3/rev up to 110 bars to move the assigned cylinder. Figure 84 shows the schematic representation of hydraulic unit including electric motor and throwing block.

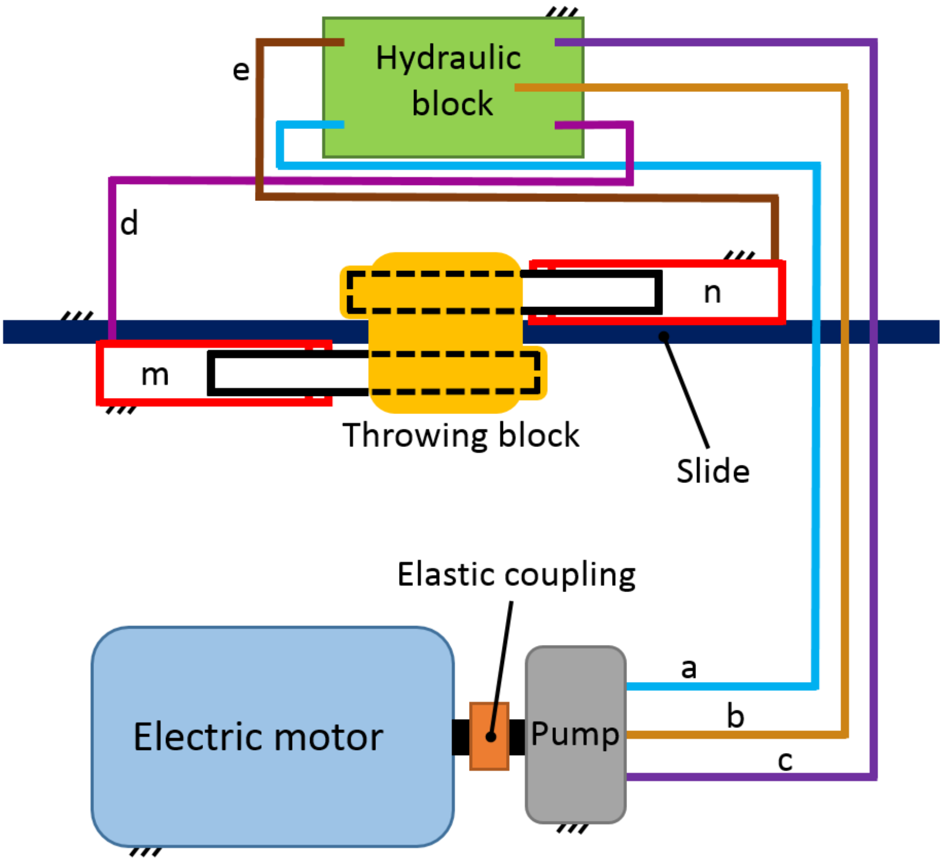


Figure 84 Schematic representation of electro-hydraulic driving unit from top view

The switch is directly driven by the hydraulic cylinders shown as ‘m’ and ‘n’ in Figure 84. When the electric motor rotates in clockwise direction, the reversible pump pressurizes the hydraulic oil through the pipe ‘c’. Pressurized oil follows the pipe ‘d’ to push the piston of cylinder ‘m’. Therefore the throwing block moves to the right on a slide which is fixed on the casing of the machine. When the motor rotates in the reverse direction, hydraulic oil is pumped through the pipe ‘a’ and it follows the pipe ‘e’ to push the piston ‘n’. During this motion throwing block moves to the left and pushes piston ‘m’ into its cylinder. The oil inside the cylinder ‘m’ goes back to the hydraulic block through the pipe ‘d’ and then follows the line ‘c’ into the pump. The same logic is valid for the cylinder ‘n’. In summary, each hydraulic cylinder serves as an oil tank for the other. The pipe ‘b’ routed between the pump and the hydraulic block is the return line. Excess oil inside the pump is carried through this line to the hydraulic block and this also prevents cracking of the pump casing.

Throwing block consists of several parts and driving rods are integrated on it. This provides them to move together with the throwing block. Therefore throwing of the point blades are directly achieved by the motion of hydraulic pistons without need of any force reducing or amplifying mechanism. Figure 85 illustrates the installed position of the driving rods on the throwing block.

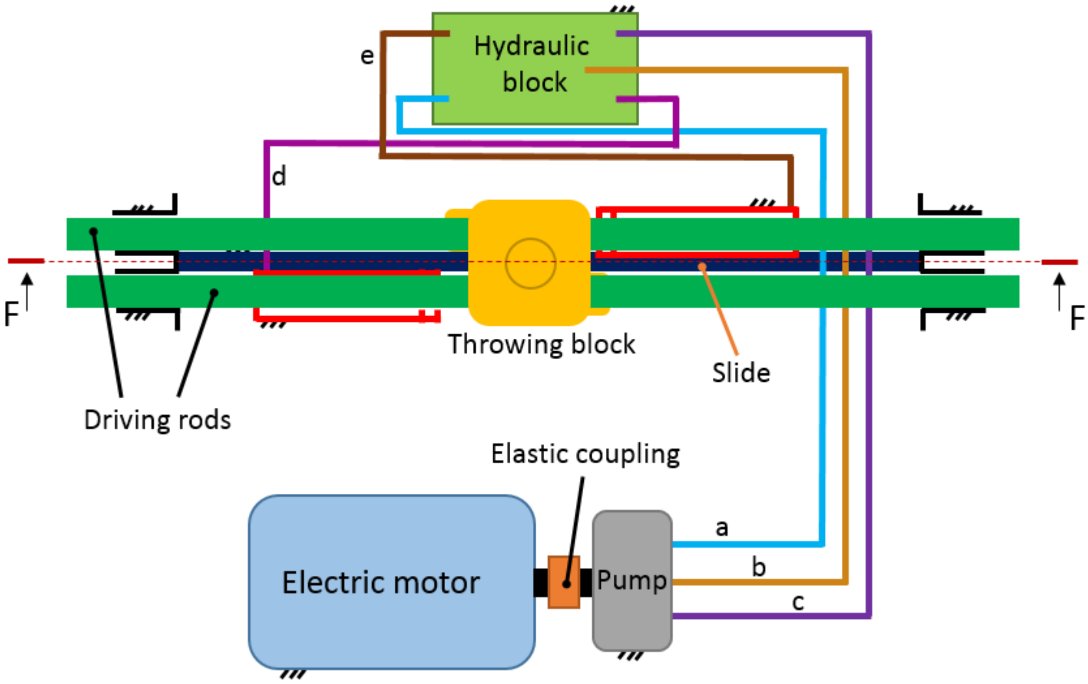


Figure 85 Schematic representation of installation of driving rods from top view

Details of the driving rods' integration with the throwing block are shown in Figure 86. It represents the section view F-F that is given in Figure 85. The mechanical parts are numbered and these numbers represent the links of the mechanism one by one.

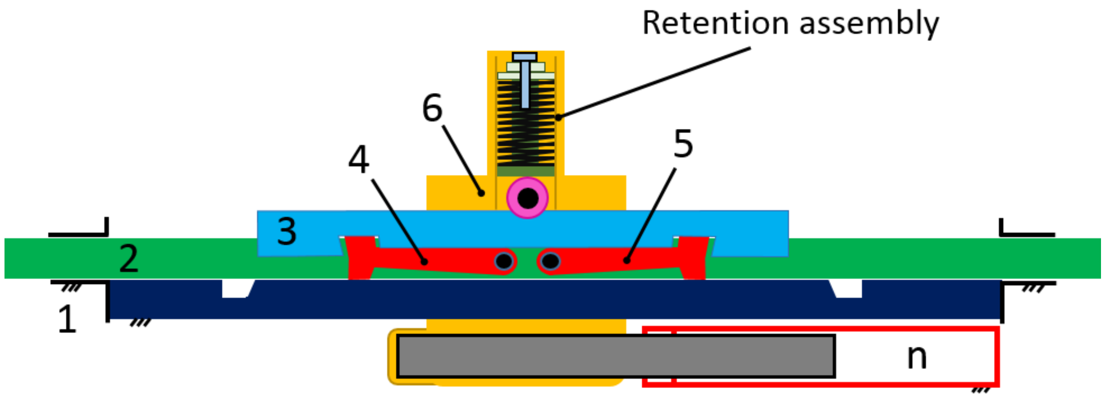


Figure 86 Schematic representation of driving rods' integration with the throwing block in front view

The link number 1 shown in Figure 86 represents the ground, namely molded casing and other parts which are fixed on it. Since the slide is essentially fixed on the casing with fastener elements, it is also indicated as link 1. While link 2 stands for one of the driving rods seen from the view F-F, second driving rod cannot be seen from that section view. The link numbered as 3 is the shutter plate. It drives the driving rods by pushing the locking clamps shown as links 4 and 5 by means of the seats underneath it. Each locking clamp is mounted on a discrete driving rod with a revolute joint type of bearing individually. For example, if the link 4 is connected with the driving rod number 2, the link 5 is mounted on the other driving rod which is not seen in Figure 86 and independent from the link 2. This means that the two driving rods have the ability to move independently of each other. The thing that they are forced to act together is the shutter plate, in fact the engagement of the locking clamps with the seats underneath the shutter plate at the same time like shown in Figure 86. However there is a backlash of about 12 mm allowing the driving rods to move independently relative to each other. Link 6 is actually a subassembly and called as retention assembly. It includes a compressed spring mechanism to push down the cylindrical bearing into the seat on the link 3. The lower side of the link 6 describes the casing of the throwing block and it is mounted with the retention assembly by bolts. Therefore they move together as if they are a single block. It is directly exposed to the pushing of hydraulic pistons shown by m and n during the operation of the machine.

Before going into details of analysis of the driving mechanism, free body diagrams of the related links are drawn. Figure 87 shows the free body diagram of throwing block including its casing and retention assembly. Since these are connected with bolts, it is assumed that they behave like a single rigid body. F_i represents the input force applied by the hydraulic piston under the effect of pressurized hydraulic oil. Fx36 and Fy36 are the reaction forces of the link 3 on the cylindrical bearing in the horizontal and vertical axes, respectively. Fy36p and Fy36r are the reaction forces of link 3 occurring at the left and right edges of the link 6.

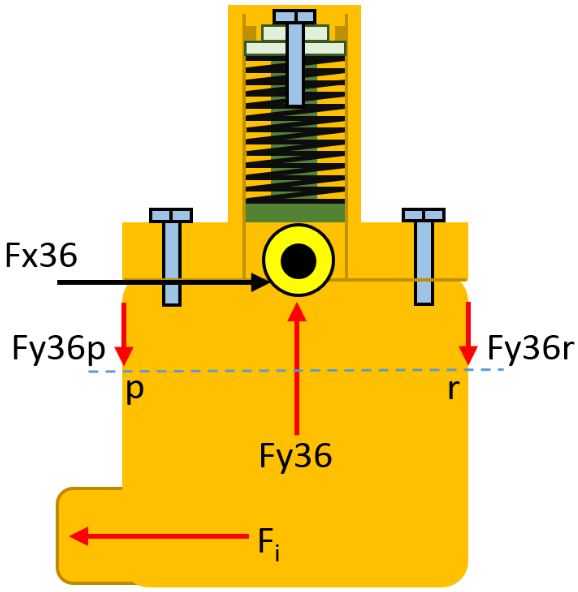


Figure 87 Free body diagram of throwing block

Figure 88 presents the free body diagram of link 3 and applied forces on it. Fx63 and Fy63 are the reaction forces of link 6 on the link 3. Similarly Fy63p and Fy63r show the other reaction forces of throwing block at the bottom side of shutter plate. Finally Fx43 and Fx53 are the horizontal reaction forces of link 4 and link 5 at the seats of link 3. At the beginning of the operation of the machine from one of the locked positions, one of these horizontal forces appears first. After the backlash between the driving rods disappears, the second locking clamp contacts with the shutter plate and its reaction force is taken into account.

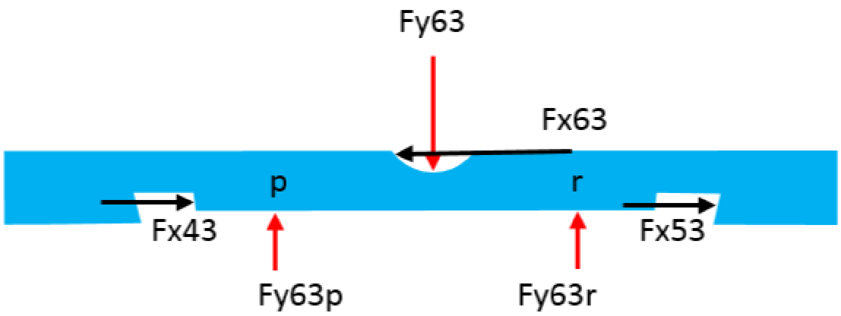


Figure 88 Free body diagram of shutter plate

Free body diagram of link 4 is illustrated in Figure 89. Reaction force of shutter plate on the locking clamp is shown as Fx34 and the reaction force of driving rod on the connection point is represented as Fx24. These forces create a moment on the link 4 and this moment is balanced with the reaction forces created by the links 1 and 2. Two forces of equal magnitude are placed at the reaction points in opposite direction and shown as Fy14 and Fy24 to create a couple moment to counter-balance the moment created because Fx34 and Fx24 are not collinear.

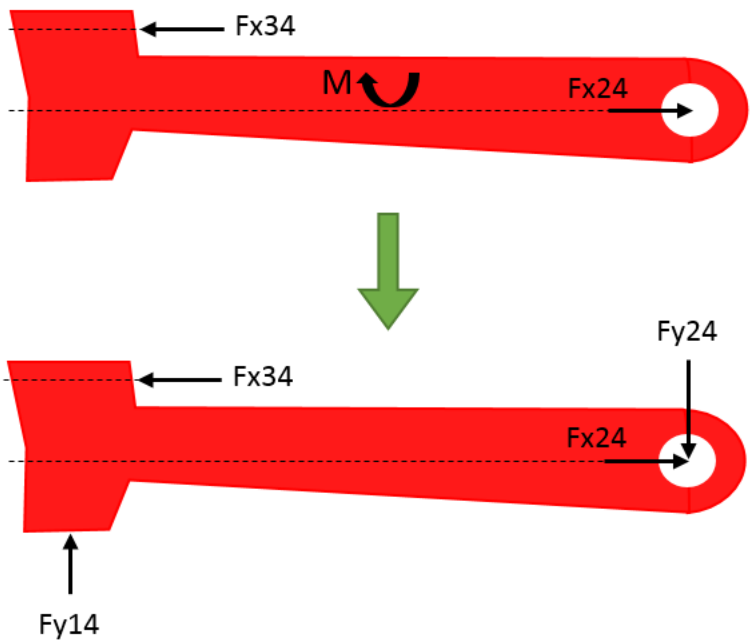


Figure 89 Free body diagram of left locking clamp

Similar to link 4, free body diagram of link 5 is presented in Figure 90. Since the link 5 is mounted on the driving rod which is not seen in Figure 86, the link number of that rod is assumed as 7. Therefore reaction forces of that driving rod on the right locking clamp are identified according to its link number 7. Horizontal reaction force of link 3 on the link 5 is shown as Fx35 and the reaction force of driving rod on the connection point is represented as Fx75. The moment created by these forces is balanced with two forces of equal magnitude but opposite directions to create a couple moment as shown in Figure 90.

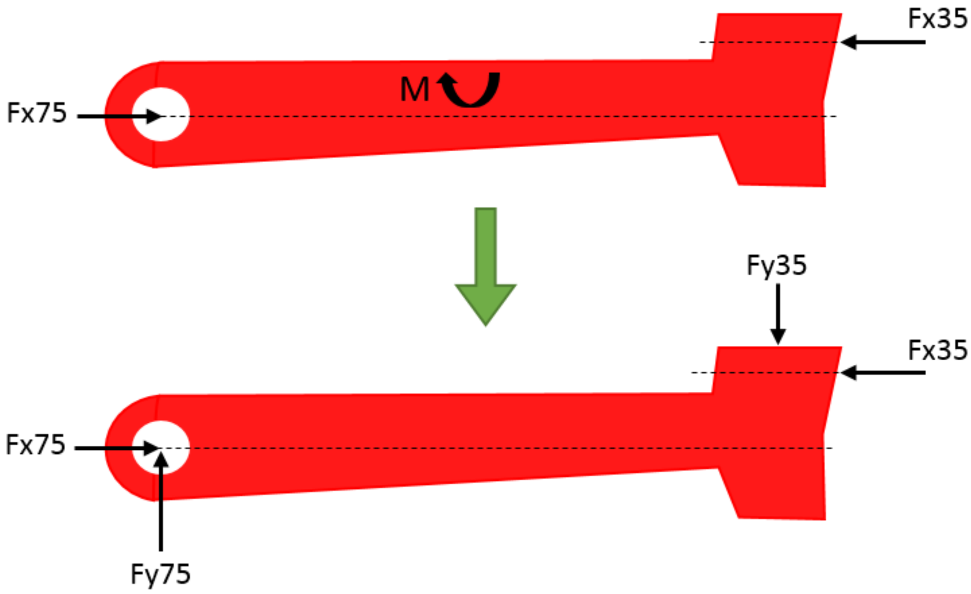


Figure 90 Free body diagram of right locking clamp

The forces applied on the driving rod (link 2) are identified in Figure 91. Reaction forces of left locking clamp on the driving rod are shown as Fx42 and Fy42. Resistive force of point blades at the tip of the rod is represented as F_{o2}. Vertical reactions of the linear bearings at two ends are also placed on the diagram.

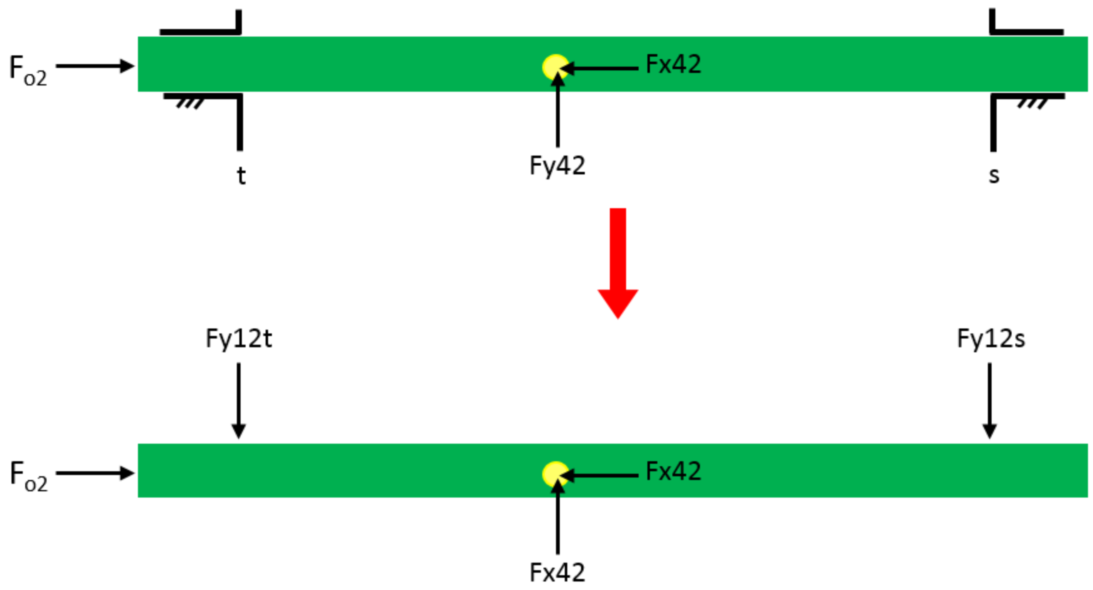


Figure 91 Free body diagram of driving rod (link 2)

Finally free body diagram of the second driving rod is presented in Figure 92. Similar to first one, reaction forces of right locking clamp on the driving rod are shown as Fx57 and Fy57. Resistive force of point blades at the tip of the rod is shown as F_{o7}. Vertical reactions at the linear bearings are also included on the diagram.

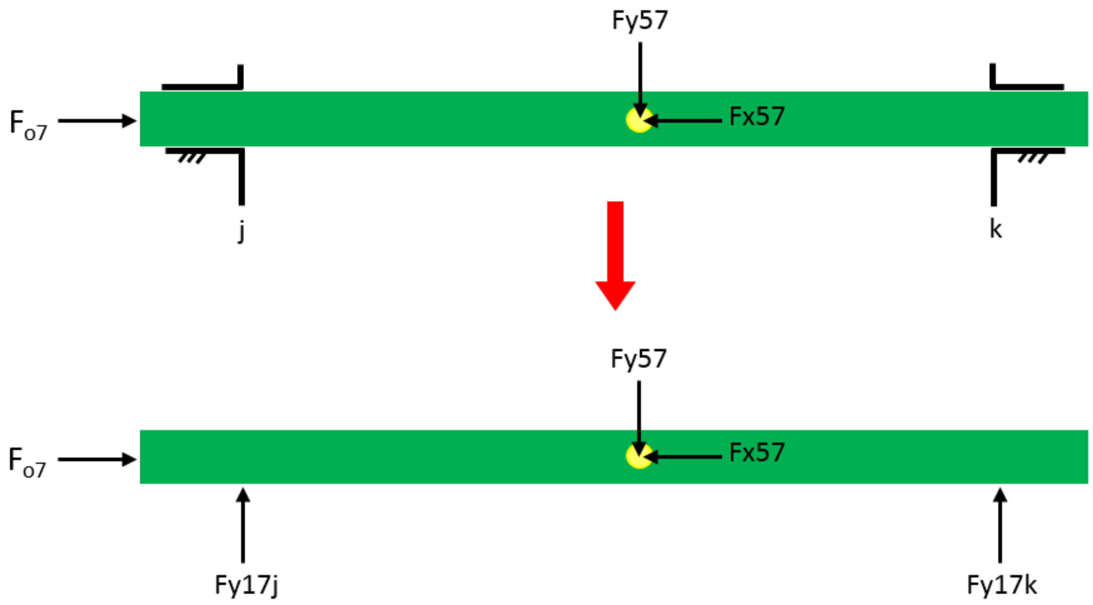


Figure 92 Free body diagram of driving rod (link 7)

After defining the links and their free body diagrams, a Matlab code presented in Appendix C.3 is written to characterize the motion of driving mechanism and applied forces on it.

In addition to known parameters like rotational speed of the electric motor, flow rate and maximum operational pressure of the pump; piston diameters of the hydraulic cylinders ‘m’ and ‘n’ are measured as 28 mm. Throwing distance of the machine is also measured by operating it with a hand crank. The stroke of the driving rods is observed as 163 mm. These known and measured parameters are used to calculate the throwing time of the machine by means of the Matlab code presented in Appendix C.3 Operation time of the machine is found as approximately 4 seconds and the throwing position of the driving rods during the operation of the machine is presented in Figure 93.

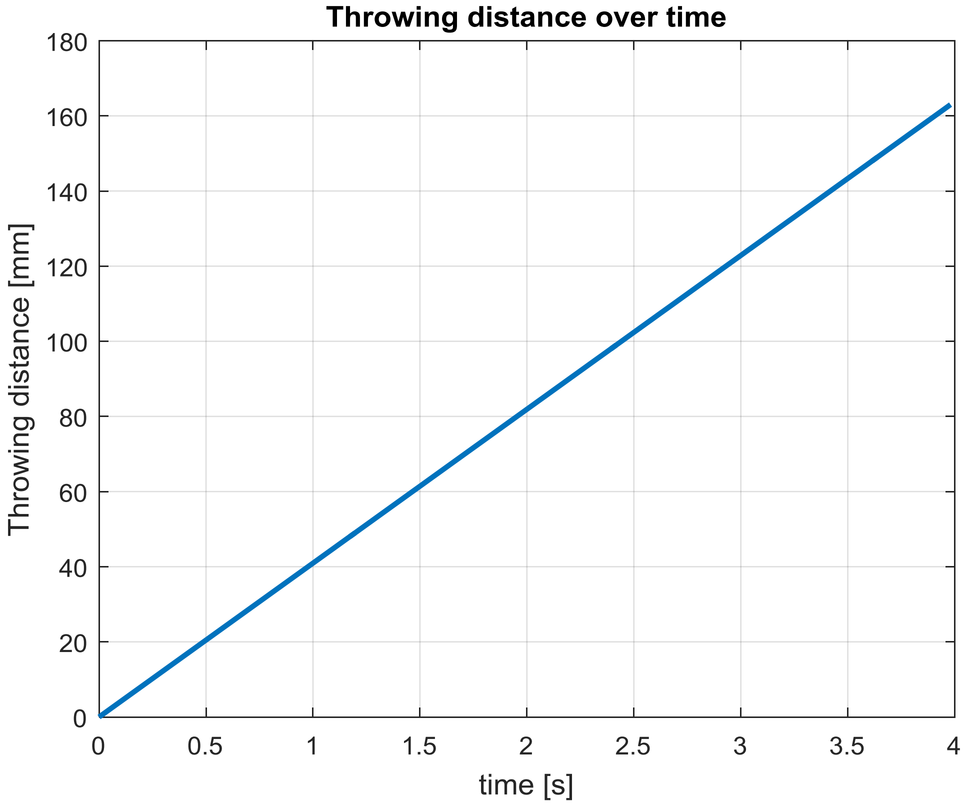


Figure 93 Throwing distance during the operation time of Point Machine C

The force applied by the pressurized oil inside the hydraulic cylinder is transferred to the link 6 through the pistons and this force indicated by “F_i” is found about 6.77 kN. Since it depends on the piston area and applied pressure by the pump, input force does not change. This force is transferred to the driving rods by the help of throwing block, shutter plate and locking clamps. Figure 94 shows the locked position of the machine at the right hand side. When it is desired to change the position of the point blades, the point machine is operated towards to opposite side. Input force applied by the hydraulic piston pushes the bottom side of the link 6 and this force is transferred to the link 3 by means of retention assembly pushing down a cylindrical bearing by compressing it into the seat on the link 3. Horizontal force on the link 3 is then transferred to the driving rod number 2 first with the interaction of locking clamp (link 4) at the left hand side seat underneath the shutter plate. While the driving rod numbered as 2 moves to the left, other one cannot move since it is connected with the link 5 and link 5 is clamped into the right-hand seat of the slide. Therefore only one of the driving rods starts to move at the beginning of the machine operation from one of the locked positions until the right-hand seat of link 3 aligns with the link 5. From then on link 5 gets out of the seat at the bottom by sliding on its inclined surfaces and it is forced to enter the right-hand seat of link 3. At that time, the second driving rod which is connected to link 5 starts also moving to the left and both driving rods act together until the link 4 falls into left-hand seat on the slide.

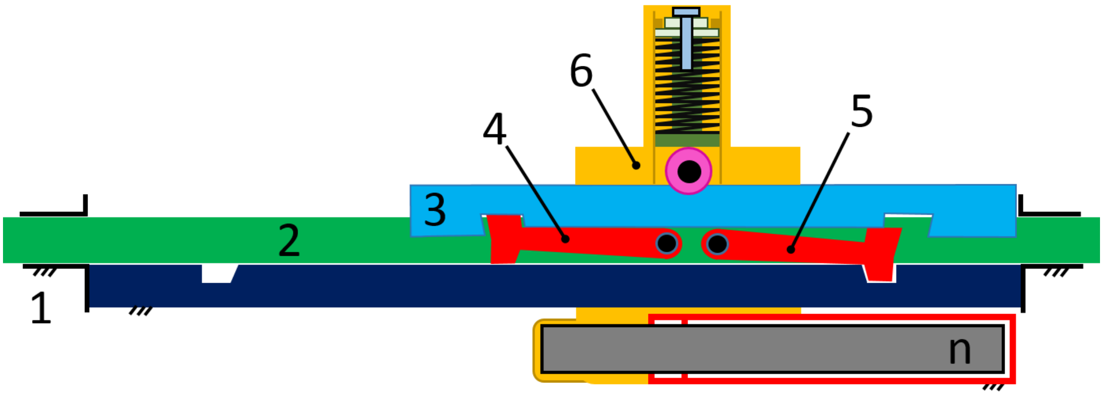


Figure 94 Schematic representation of one of the locked position of the machine

When it falls into the left-hand seat as shown in Figure 95, movement of the link 2 stops but the other driving rod which is connected to link 5 continues to move until the link 3 leans the casing of the machine at the left hand side. Finally, operation of the machine is completed when the link 4 is clamped into the seat by shutter plate at the leftmost position.

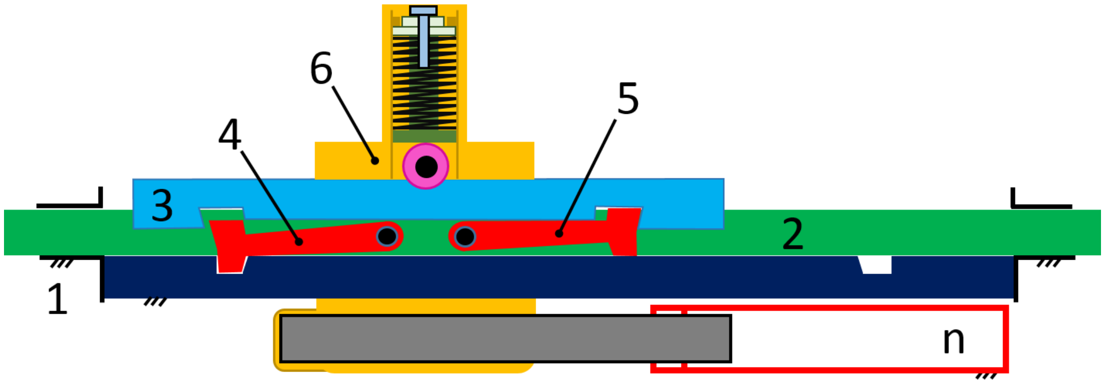


Figure 95 Schematic representation of falling of locking clamp into a seat

Since the two driving rods move individually at the very beginning and at the very end of the operation, they are exposed to a force directly equaling to input force applied by the hydraulic piston which is 6.77 kN at that small time intervals. However in the majority of operation period, input force is balanced with the reactions of both driving rods.

During the operation of the machine, throwing block slides in the fixed slide with the constraints of prismatic joint between them. The two driving rods move in the linear bearings placed on the machine casing and the kinematic joint between driving rods and casing is described as prismatic joint. At the same time, the driving rods also slide through the throwing block and this joint also represented as prismatic joint. In addition to these, the kinematic relation between the shutter plate and the throwing block is constructed with a prismatic joint. This means that redundant joints are present in this driving mechanism. Since the redundant constraints are present in the mechanism, the system is statically indeterminate. Although redundancy has been regarded as a desirable property to ensure the safety of such structural systems, it is not possible to analyze them by mere use of basic equilibrium equations. The more detailed force analysis is not included in this study because joint reaction forces are not important.

There are some frictional forces at the joints and mechanical contacts while the mechanism is in motion. Since there are radial bearings or bushings at the revolute joints and low frictional superficial contacts between the friction surfaces of the links, these force are negligibly small compared to operational forces of the machine. Other than these, the frictional force at the circular linear bearing between the driving rod and the casing of the machine is measured by using a force measurement device. This measurement is repeated ten times in order to be sure that the measurements are coherent. Figure 96 shows a photograph taken during one measurement. The friction force at the linear bearing was measured as 30 N at average while it is moving. The maximum force is measured as 40 N at average and it is observed at the impending motion of driving rod. Finally if the friction forces at the slides are excluded from the applied load on the driving bar, the net force applied on the point blades by the driving bar is found about 6.7 kN.

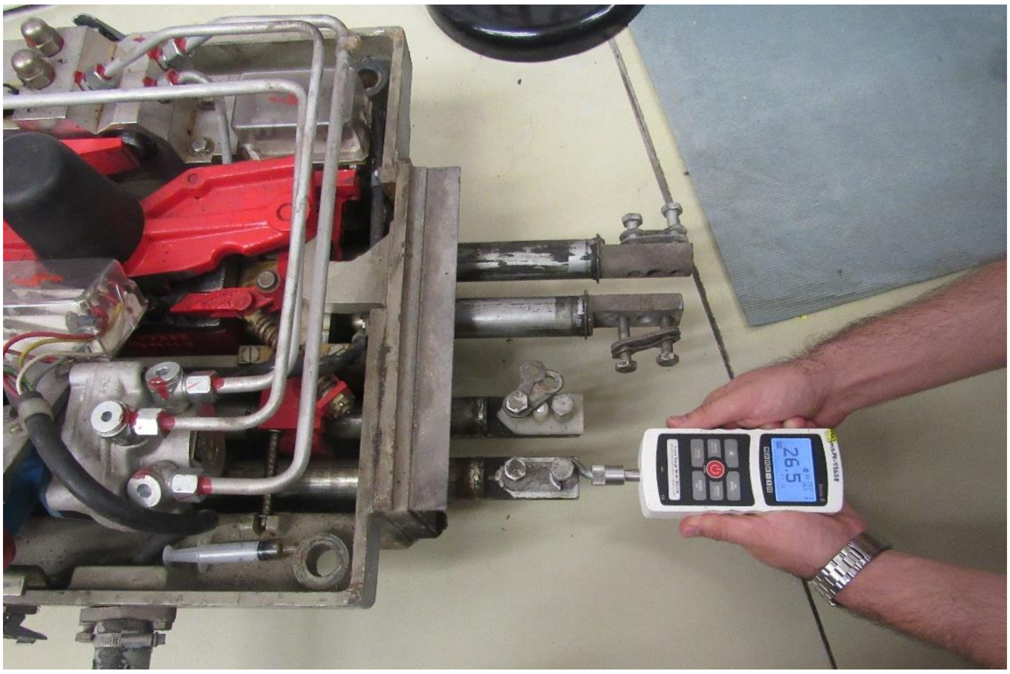


Figure 96 Force measurement at the linear slides

As described at the beginning of this chapter, there are two detector rods having circular cross sections to supervise the correct position of the point blades one by one.

One of them is mechanically connected to tip of the near point blade and the other one is connected to tip of the distant point blade by means of a mechanical linkage. When the blades of the point come to one of the end positions and the engagement occurs with the stock rail, a locking mechanism is activated automatically at these positions. Indeed the locking mechanism locks the two detector rods which are mechanically connected to point blades. Therefore the motion of the point blades is prevented and the point is locked. The reason why there are two detector rods is to check the positions of both point blades independently. The locking mechanism does not work if one of the detector rods, in fact the point blades, is not at the exact desired position. It works only when both of the point blades are at the exact desired position.

In addition to this, there is a mechanism which locks the throwing block indicated by link number 6 to avoid acting of driving rods at the end positions. Since the motion of driving rods depend directly on the throwing block, it is ensured that the motion of the point blades is prevented also by locking the throwing block. Locking of the driving rods and locking of the detector rods are performed simultaneously. Figure 97 shows the whole locking mechanism together with the detector rods.

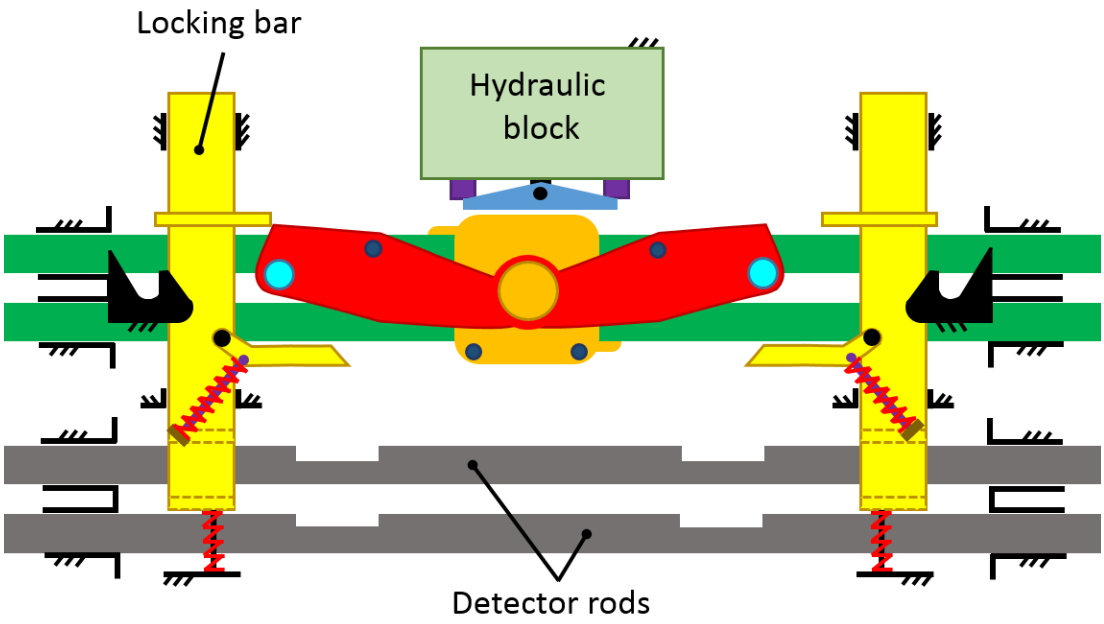


Figure 97 Schematic representation of whole locking mechanism

In order to succeed the locking of driving rods, a part named as “rocker” is installed on the throwing block at the same center with retention assembly as illustrated in Figure 98. The rocker is free to rotate about its mounting center. There are two bushings placed on both ends of the rocker and they are referred as “rocker rollers”. Rocker rollers can also freely rotate about their own axes. There are also two bushings smaller than the rocker rollers and they are named as “bolt”. The “activators” are another pin type of bushings mounted on the corners of throwing block. Bolts and activators can also rotate freely about their axes like rocker rollers. Two “locking recesses” are installed at both ends of the machine casing to receive the rocker rollers into their seats at the locked positions of the machine. There is also a part called “revolver” on the hydraulic block that can rotate about a revolute type of joint by the help of “revolver pistons” fed from the inside of hydraulic block.

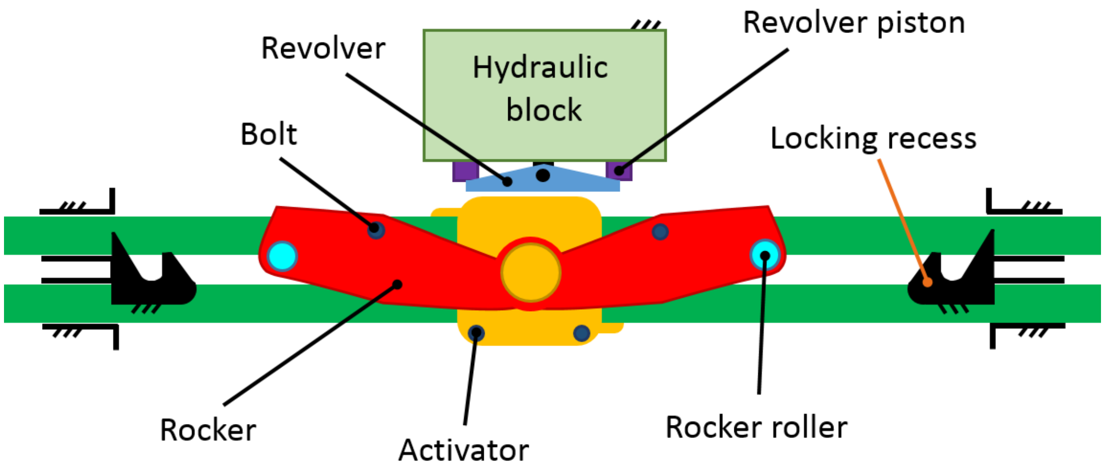


Figure 98 Schematic representation of locking mechanism for driving rods

Locking of the detector rods are achieved by means of "locking bar" and other functional parts on it as illustrated in Figure 99. "Compression arm" is the key component that is mounted on the locking bar with a revolute joint. It provides a force required to move the locking bar in the locking direction by rotating about its mounting center and pressing the "compression spring". The part referred as "pusher" is welded on the locking bar and used to put the rocker roller into the locking recess by pushing the bolt on the rocker with the help of locking bar motion. There is a "recoil spring" installed between the molded casing and the tip of locking bar. Normally it is in compression of about 10 mm to keep the machine unlocked. However it is compressed about 15 mm more by the locking bar when the machine is locked. Spring constants of the "compression spring" and "recoil spring" are compared by compressing them from their free lengths. Springs are compressed equally about 5 mm and the restoring forces exerted by them are measured. The spring constant of compression spring is measured as 25 N/mm while the spring constant of recoil spring is about 5 N/mm. These measurements are repeated at least five times in order to be sure that the measurements are coherent. It is concluded that the spring constant of the compression spring is 5 times larger than that of recoil spring.

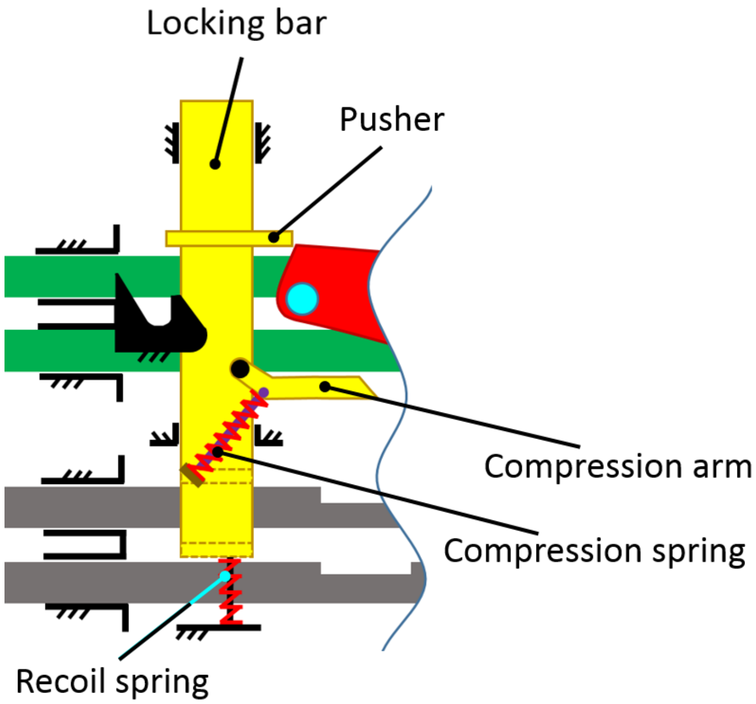


Figure 99 Schematic representation of locking mechanism for detector rods

When the machine is operated, for example, to the left position by feeding the assigned hydraulic cylinder, the rocker on the throwing block also moves to the left depending on the motion of driving rods. Figure 100 shows the contact position of rocker roller with the locking recess at the left hand position of the machine.

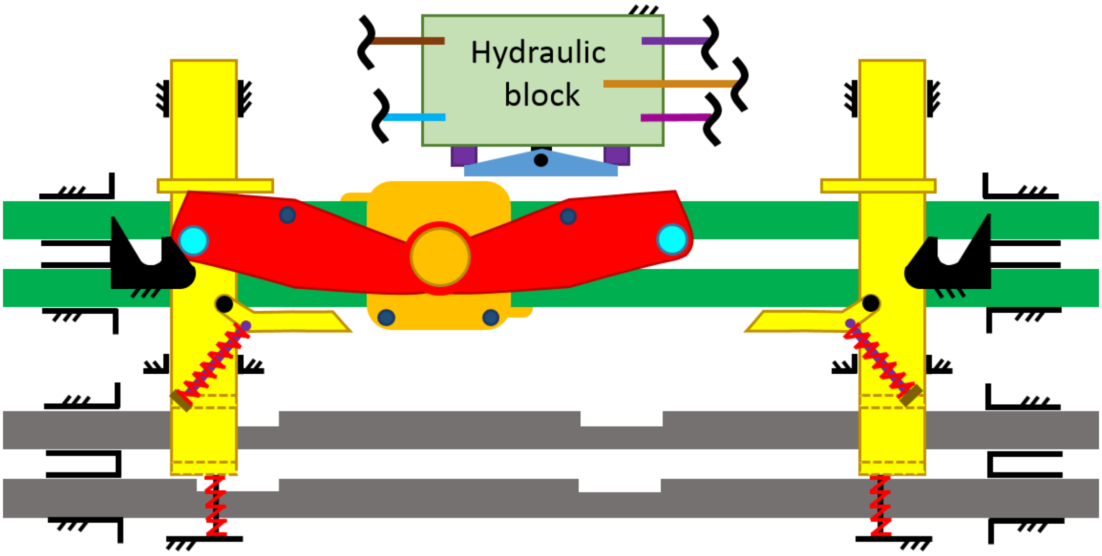


Figure 100 Contact position of rocker roller with the locking recess

While the operation of the machine continues to the left, rocker roller slides on the inclined surface of locking recess and the rocker slightly rotates about its center. When the rocker roller completes its climbing on the inclined surface of locking recess, the bolt on the rocker is in touch with the pusher. This prevents further rotation of the rocker about its mounting center. Meanwhile the activator on the throwing block begins to contact with the compression arm and then it rotates the compression arm about the mounting revolute joint by climbing its inclined surface and compressing the compression spring. Figure 101 presents the position at which the compression spring is compressed to activate the locking bar in the locking direction by the activator on the throwing block just before the lock.

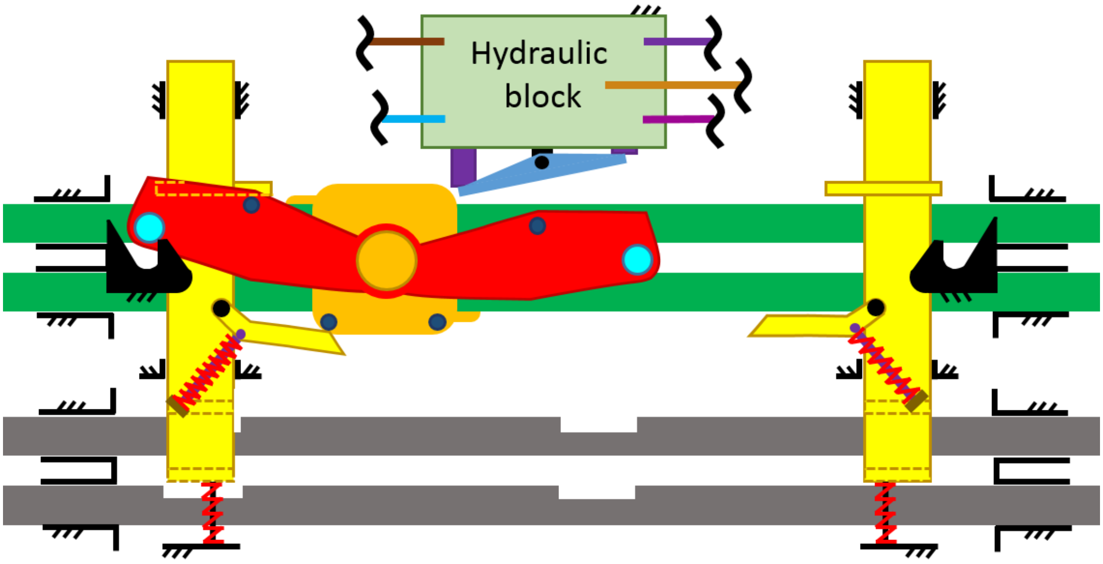


Figure 101 The position of the machine just before the lock

Finally the rocker roller is received into the locking recess and the locking bar slides in the locking direction because of the compressed compression spring. Even if the compression spring is mounted on the locking bar at an angle of about 45 degrees, the force on the locking bar exerted by it is more than enough to overcome the force exerted by the compressed recoil spring due to excessive difference in their spring constants. Figure 102 illustrates the locked position of the machine at the left hand side.

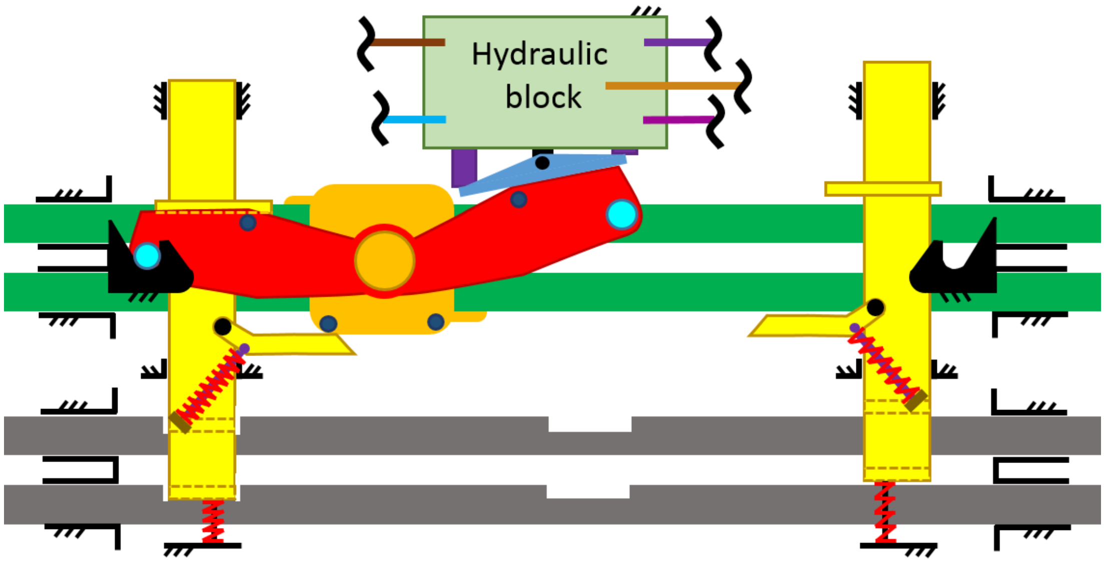
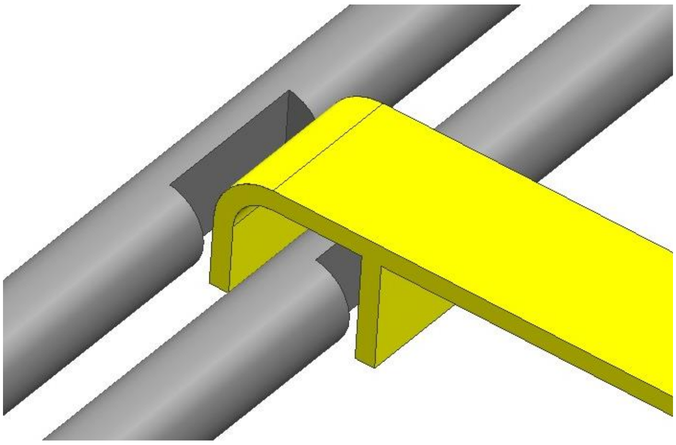
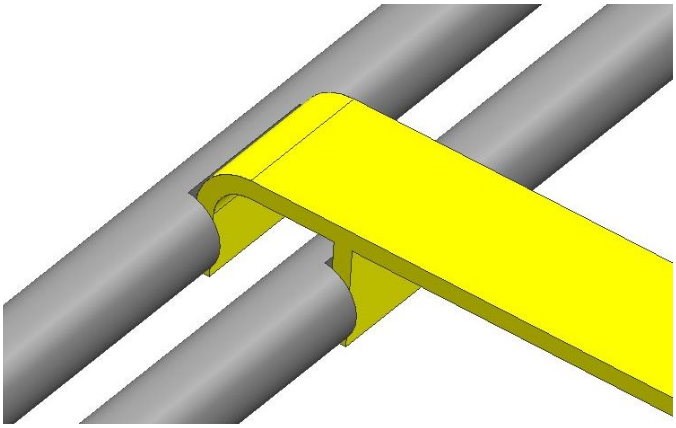


Figure 102 Locked position of the machine at the left position

The two detector rods having a diameter of 35 mm are also locked at the end positions of the machine. Each detector rod has two seats whose depths are 15 mm to receive the protruding tips of the locking bar. When the machine completes its operation, meaning that the point blades come to one of its end positions, the seats on the detector rods align with the locking bar. Therefore protruding tips of the locking bar are pushed in these seats. Unlocked and locked positions of the detector rods are shown in Figure 103.



(a)



(b)

Figure 103 Unlocked (a) and locked (b) positions of the detector rods

Since the distance between the seats on the detector rods and the distance between the locking recesses are constant, throwing distance of the machine could not be adjusted. Therefore this point machine can only be used on the points having an arrangement clearance of 163 mm.

When it is needed to change the position of the point, the point machine is operated towards the opposite side. In order to unlock the locking mechanism, the electric motor is driven in the reverse direction and thus the hydraulic oil is pumped into the assigned hydraulic cylinder to move the throwing block. However it cannot be moved since the rocker roller is still inside the locking seat. Therefore pressurized oil fills first into the assigned revolver piston to take out the rocker roller from the locking seat by rotating the revolver about its mounting center on the hydraulic block. This provides the rocker roller to get out of locking recess by pushing the locking bar in the unlocking direction. Figure 104 shows the unlocked position of the machine just before the acting of driving rods. This unlocking operation guarantees that the motion of the driving rod is restricted while the mechanism is unlocking. When the rocker roller gets out of the locking recess completely, the driving rods start to move to the other end position. When the throwing motion of the blades is finished, the locking mechanism at the opposite side is again activated.

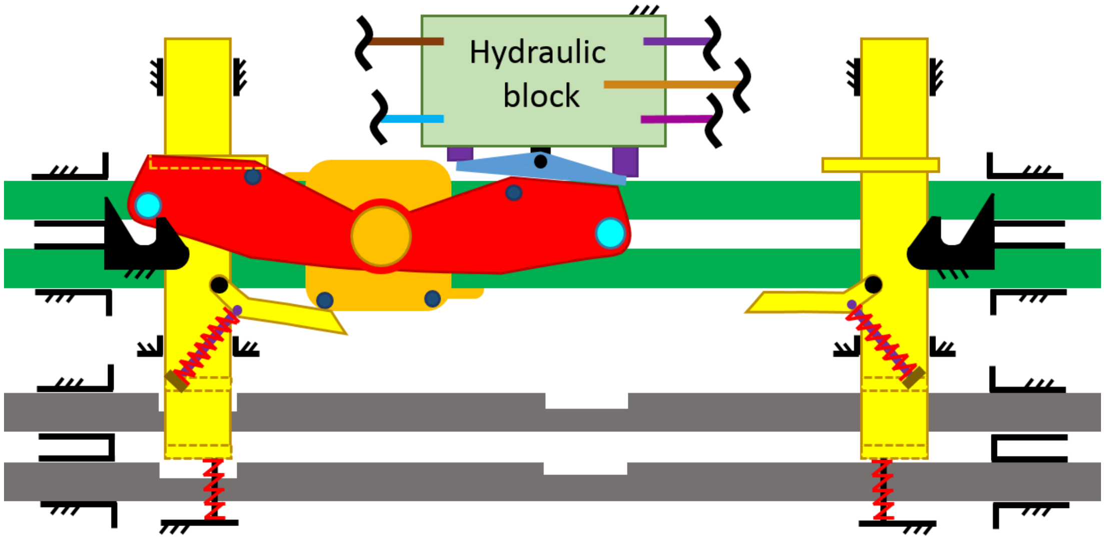


Figure 104 Schematic representation of the machine at the just unlocked position

There are two electrical contact switch pairs installed in the casing just tip of the locking bars at each sides. These switch pairs are used to inform the control center whether the machine is locked or not at the end positions of the machine. The lower contact switches in each pair are normally closed while the machine is in operation as illustrated in Figure 105. The upper ones are kept open with the help of small pins mounted on the locking bars.

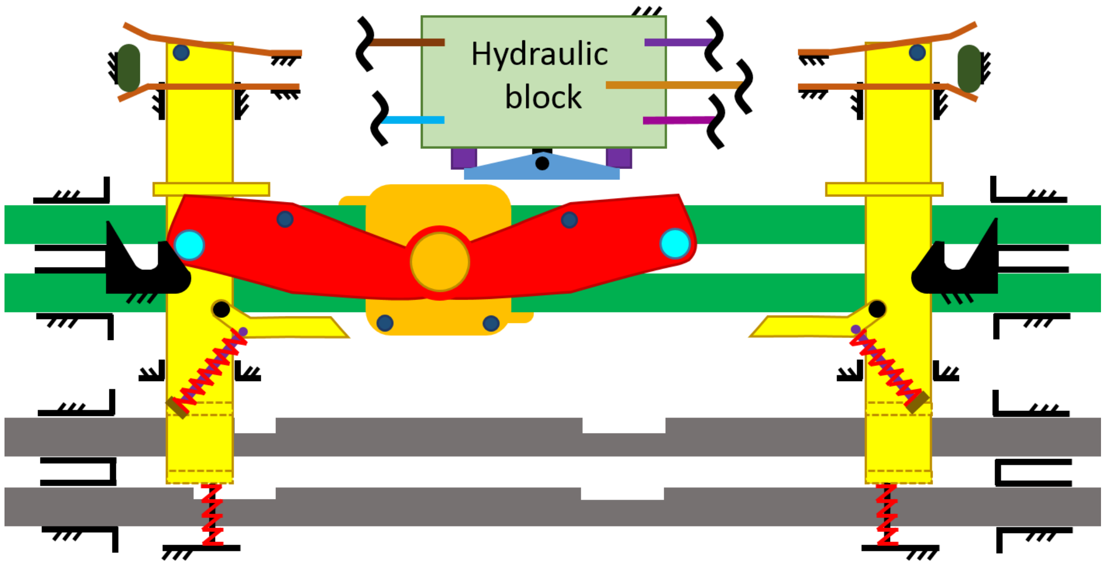


Figure 105 Position of the contact switches during the operation of the machine

When the machine comes to one of its end positions and locked by the locking bar and the rocker, the small pin on the locking bar pushes down the lower switch and the contact is broken. At the same time, the upper one is released and switch is automatically closed. As a result of this, a signal is sent to the control center stating that the machine is locked. Figure 106 shows the positions of the contact switches when the machine is locked at the left hand side.

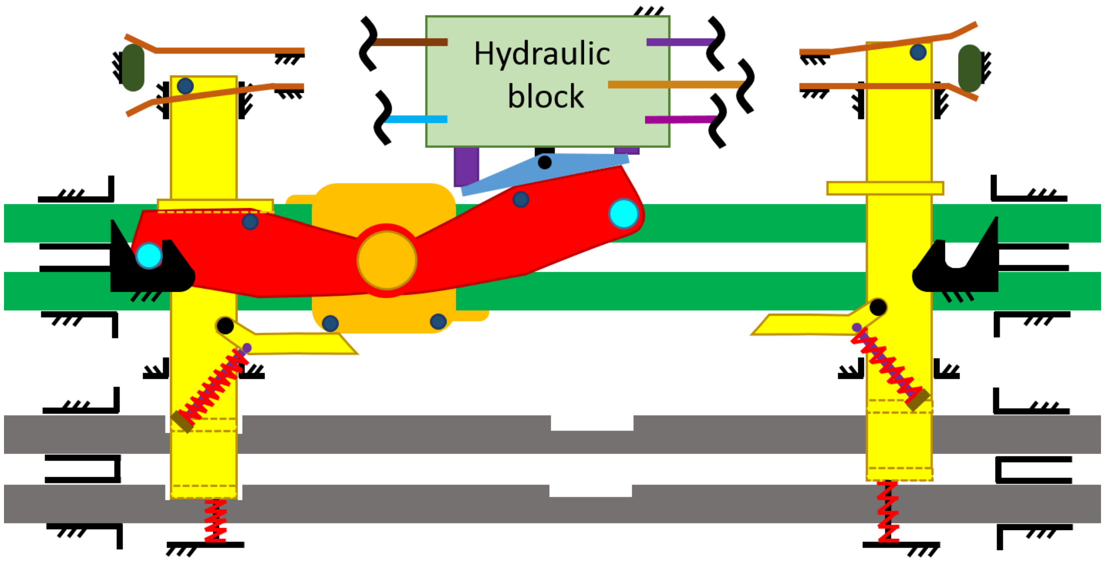


Figure 106 Locked position of the contact switches at the left hand side

There are also four similar contact switches mounted on the electric motor to cut off the supply energy in the case of manual operation of the machine by using the hand crank. When the machine is required to operate manually in the case of a fault or for other reasons, the electric motor is driven by using the bevel gear mounted its output shaft with the help of a crank. In that case, the supply energy is cut off in order to operate the machine safely. Figure 107 presents the photograph of energy cut-off switches and the access hole for the manual hand crank.

There is no detection function to check the contact problems of these switches caused by oxidation, arching or wire break. A governing signal is generated in a proper operation to make aware the control center when the throwing of the machine is completed. Not receiving the governing signal can be considered as an indicator of an operational problem although the operation command is sent to the point machine. The electric motor, locking mechanism, contact switches or any other component inside the machine may be the reason of problem. This requires in-situ examination on the point machine to understand the reason of fault.

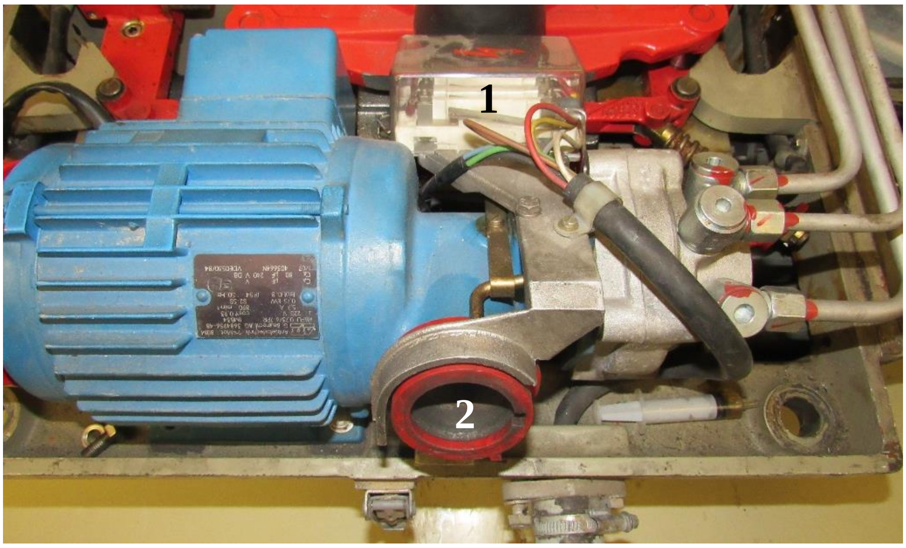


Figure 107 Energy cut-off switches (1) and access hole (2) for the manual operation

A bevel gear pair is used in order to rotate the motor shaft from the side. One of the bevel gears is mounted on the motor shaft and its pair is on the hand crank. When the hand crank is inserted through the access hole, the two bevel gears form a pair and the rotation of crank is transmitted to the motor shaft by changing the direction of rotation 90 degrees. The usage of hand crank is schematically illustrated in Figure 108.

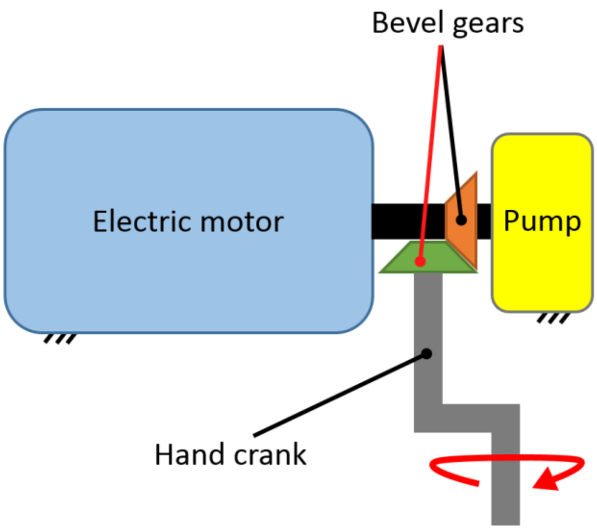


Figure 108 Schematic representation of the use of hand crank

There is an energy cut-off ring having a small seat like a keyway at the inner surface of it and the ring is mounted at the entrance of crank hole. There is also a similar seat at the inner surface of the hole. These two seats have to be aligned by rotating the energy cut-off ring in the counterclockwise direction in order to insert the hand crank through the access hole. Positions of the ring for both normal and manual operations are shown in Figure 109.

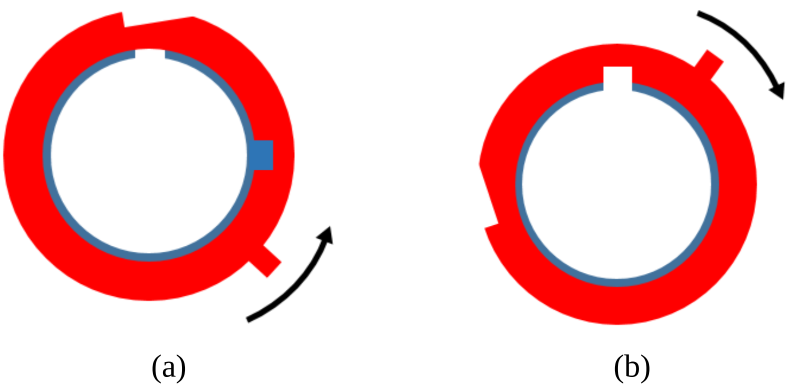


Figure 109 Position of the energy cut-off ring in normal (a) and manual (b) operations

As can be seen in Figure 109, there is a small recess having an inclination on the outer surface of the ring and a thin rod settles there. The thin rod is mounted on the fixed frame such that other end of the rod lies down the contact switches and it can be rotated about its mounting point. When the energy cut-off ring is rotated in the counterclockwise direction for the manual operation, it forces to push up the thin rod shown in Figure 110 with the help of inclined recess. As a result the four contact switches are opened by pushing them up and electrical connection of the motor is broken. In this way, the supply energy is cut off and the manual operation of the machine is secured.

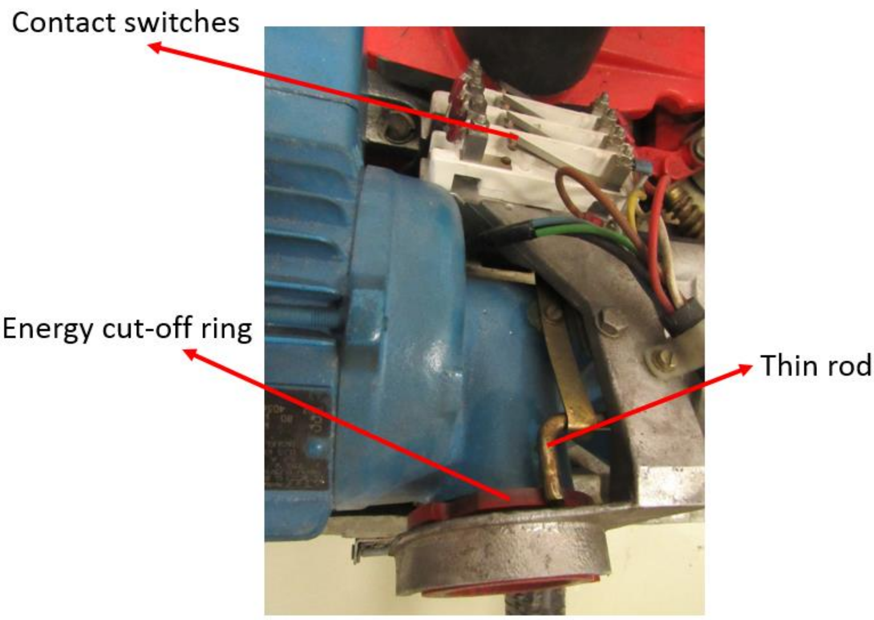


Figure 110 Energy cut-off mechanism

This point machine enables the trains to make a trailing move over an incorrectly positioned point while protecting itself. Trailing is provided by dint of the retention assembly. Retention assembly basically includes a spring housing, spring bolt, spring, trailing cylinder and a retaining force adjuster. Figure 111 illustrates the schematic details of retention assembly.

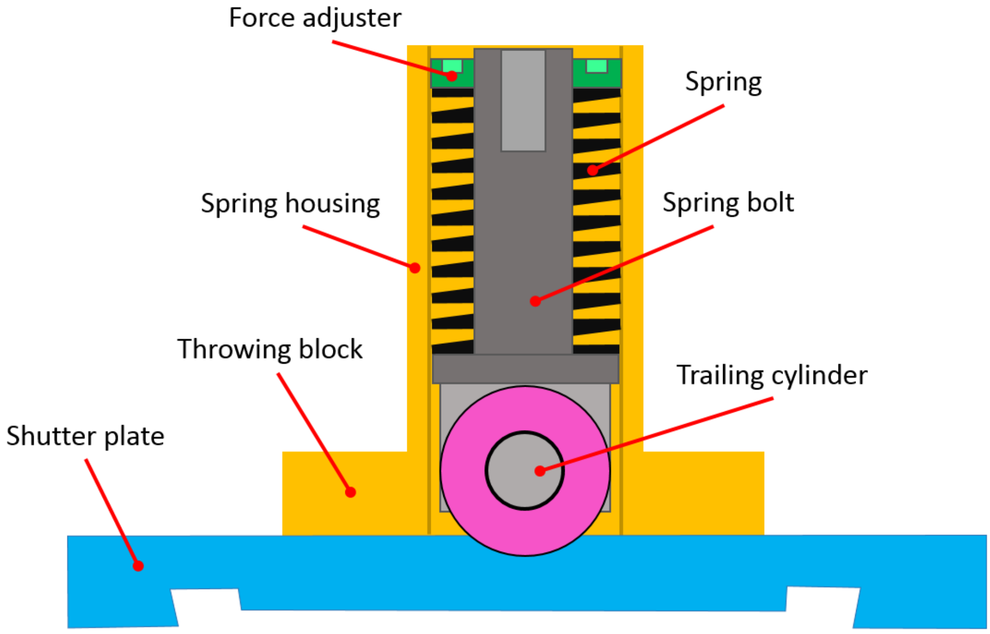


Figure 111 Components of retaining assembly

The spring housing has internal threads on its inner surface and the force adjuster is screwed in it to compress the spring. Therefore trailing cylinder is forced to stay into the seat on the shutter plate. When a train makes the trailing move over the point, shutter plate is forced by the driving rods to leave its locked position. If the shutter plate achieves to push up the trailing cylinder by compressing the spring even more, driving rods leave their locked positions and thus the train passes over an incorrectly positioned point without damaging the machine. During the trailing movement of a train, retention assembly keeps its position since it is locked by the rocker from the upper side and the throwing block is held by the hydraulic pistons from the bottom. However shutter plate escapes from the trailing cylinder together with the driving rods.

The force applied by the train on the point blades to make a trailing move is called as trailing force. This force is directly applied on both driving rods simultaneously and shown as F_t in Figure 112.

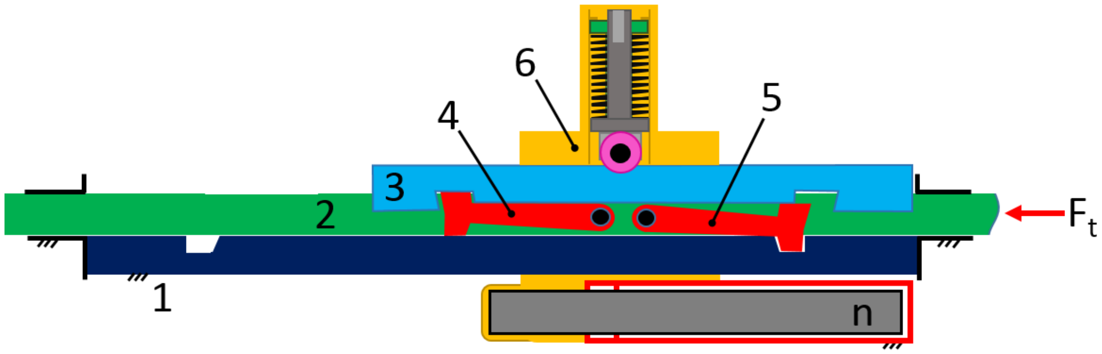


Figure 112 Trailing force acting on the driving rods

Trailing force applied on the driving rod that is connected to link 5 cannot move that rod because the link 5 is held into the seat of link 1 by the link 3 from the upper side. However the force applied on the link 2 is transferred to the link 3 by the help of link 4 since the two driving rods can move independently. Whenever the shutter plate escapes from the trailing cylinder and stands aside over the link 5, the two driving rods start to move together through the trailing direction. At the beginning of the trailing, transferred force on the shutter plate acts on the trailing cylinder. In order to perform the force analysis about the trailing motion, required geometrical dimensions of shutter plate and trailing cylinder are measured. Besides the free length and stiffness of the spring are also measured. Free length of the spring is measured as 102 mm. Then the spring is compressed vertically with a hydraulic compression machine by applying a force of 5000 N in order to determine the spring constant. The compressed length of the spring is measured as 90.1 mm. This means that the spring is compressed about 11.9 mm under the force of 5000 N. The spring constant is approximately found as:

$$k = \frac{Applied\ force}{Contraction} = \frac{5000\ N}{11.9\ mm} \cong 420\ N/mm \tag{3-16}$$

Diameter of the trailing cylinder and the depth of the circular seat on the shutter plate are measured as 35 and 5.5 mm, respectively. Figure 113 presents the mate of these components and their dimensions on them.

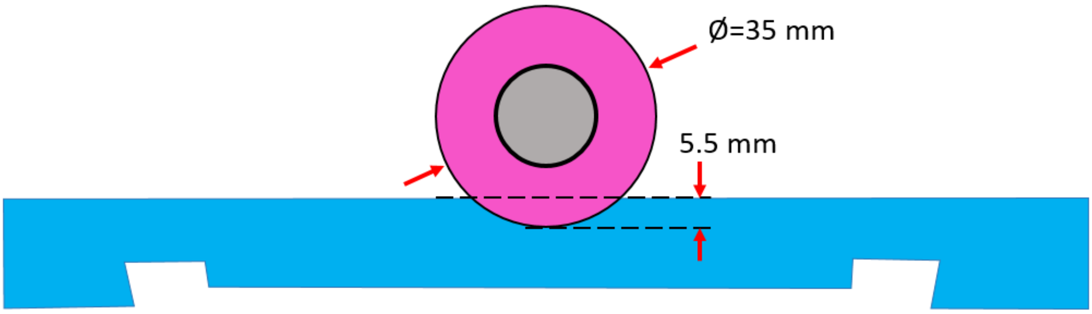


Figure 113 Mating of trailing cylinder into shutter plate seat

In order to allow the trailing movement of a train, the force applied by the train is transferred to the trailing cylinder to take it out from the seat by pushing it up. The critical force to take it out from the seat is necessarily applied at the corner point of the circular seat through the center of trailing cylinder. Free body diagram of trailing cylinder at the beginning of the trailing is shown as Figure 114.

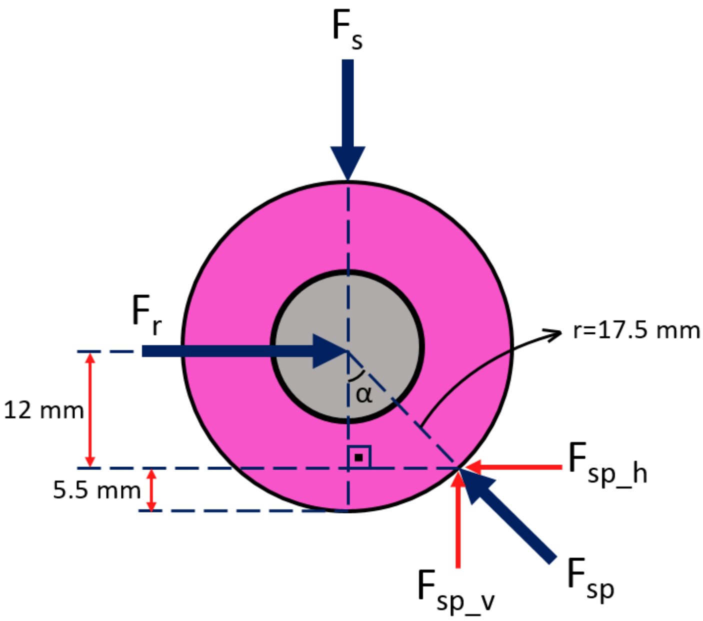


Figure 114 Free body diagram of trailing cylinder at the beginning of trailing

The force F_s shown in Figure 114 represents the spring force on top of the cylinder. Reaction force of shutter plate is shown as F_{sp} and its vertical and horizontal components are represented as F_{sp_v} and F_{sp_h}, respectively. Finally reaction force of spring bolt at the center of the cylinder is shown as F_r. Actually horizontal component of the reaction force of shutter plate is equal to the trailing force. It basically depends on the spring force applied on top of the cylinder. It is noted that the spring is compressed 5.5 mm more than that of its normal operation in order to achieve trailing movement. Additionally, compression of the spring can be adjusted by the force adjuster by screwing or getting it loose. This means that the trailing force of the machine can also be adjusted.

In order to calculate the trailing force that must be applied by the train to make a trailing move, contraction distance of the spring adjusted by the force adjuster is roughly measured between 13 and 17.2 mm. By using these collected parameters, trailing force calculations are performed with the help of a Matlab code presented in Appendix C.3 and the results show that it can be adjusted between 8.2 and 10.1 kN.

Trailable point machines, like the machine C, allow the rail vehicles to pass through the points in a trailing direction without any damage even if they are not actually arranged for that route. Nevertheless trailing is not a usual movement over an incorrectly arranged point. Rail vehicles seldom pass through the points by trailing especially at the depots and maneuver loops. If a vehicle pass through the point where the point machine C is installed by trailing, the force applied by the train on the point blades is transferred to the driving rods and the lock is released when the trailing force is reached. Since the lock is released, the governing signal at the control center disappears and hereby the dispatcher is informed about the trailing on the point. Additionally driver of the vehicle realizes the trailing when he pass through the point by trailing and he informs the staff at the control center about the situation. After the trailing movement of the train, an authorized employee has to check the point blades, stretchers, connection rods and point machine. If there is a damage to these components, they have to be replaced with new ones. Otherwise, operation of the point including the point machine and other auxiliary components has to be tested by throwing the point blades several times in both directions to be sure that the point works properly and securely.

3.4 INVESTIGATIONS ON POINT MACHINE D

The point machine D is an electro-mechanical point machine containing an electric motor, a set of gear, driving mechanism, locking mechanism and contacts. All these components are mounted in a molded steel casing and covered with a molded steel top. Moreover there are two rectangular bars operating simultaneously to drive the point blades and there are two additional rectangular bars having the same cross sections with the driving bars to inspect the correct positions of the point blades respectively. Figure 115 shows the general view of point machine D.

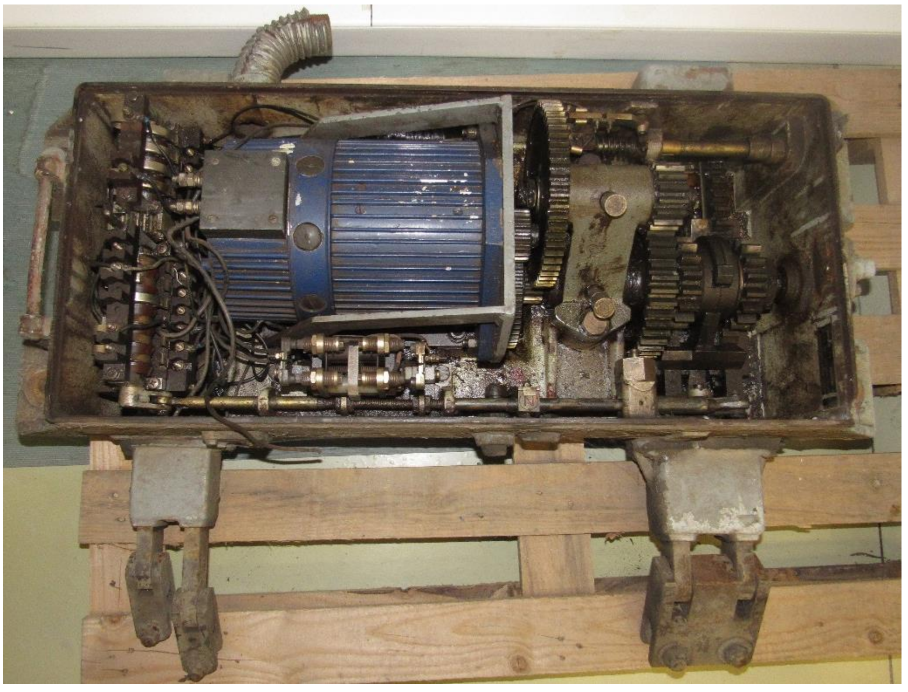


Figure 115 Photograph of inside view of point machine D

The electric motor is mounted in the middle of the machine with the help of a steel holder bracket. The motor is operated with the voltage of 24 V DC and it can produce maximum 400 revolution in a minute.

A gear set is installed in front of the motor and these gears transfer the rotational motion of electric motor to the driving pinions by reducing the rotational speed and increasing the driving torque of the motor. Throwing motion of the driving bars is basically achieved with the help of rack and pinion gear pairs.

Driving mechanism of the machine has been analyzed and a representative kinematic model is obtained as shown in Figure 116. There is a pinion gear at the output shaft of the electric motor and the number of teeth of this pinion is 20. The rotation of that pinion is transferred to the driving pinions at the end by means of several spur gear mates. The two driving pinions are installed on the same shaft and placed on top of the driving bars. The driving bars and driving pinions form two rack and pinion gear mates which operate simultaneously.

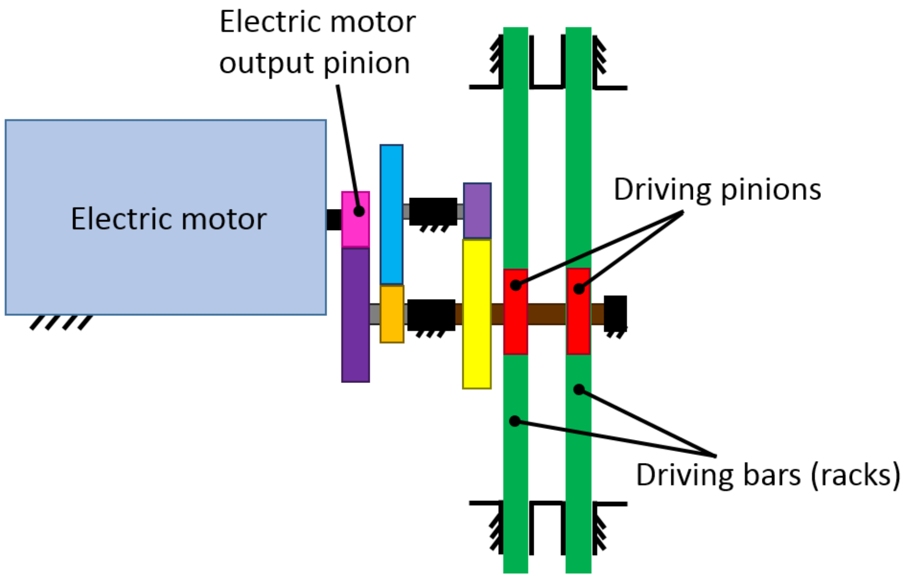


Figure 116 Representative schematic model of driving mechanism from top view

The mechanical parts of the driving mechanism are numbered and these numbers represent the machine elements of the mechanism one by one. The element numbers are shown in Figure 117.

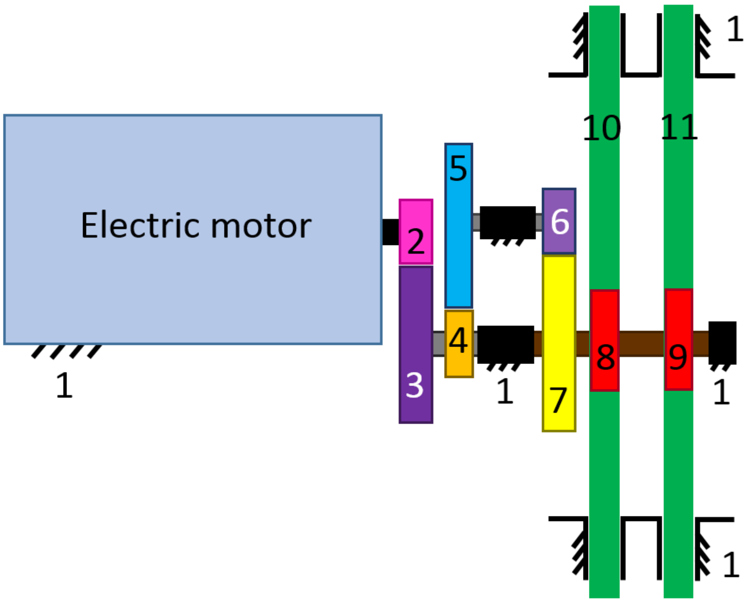


Figure 117 Representative schematic model showing the machine elements of driving mechanism

Number 1 shown in Figure 117 represents the ground, namely molded casing and other parts which are fixed on it. The gear shown by 2 represents the pinion gear installed at the output shaft of the electric motor. Number 3 shows the mating gear of gear 2. Small gear which is illustrated with number 4 forms a compound gear with the element number 3. The mating gear of element 4 is represented as gear 5. The part shown as 6 is the gear mounted on the same shaft with the gear 5. While the component 7 represents the mating gear of 6, driving pinions placed on the same shaft with the gear 7 are described as element numbers 8 and 9. Finally the components 10 and 11 show the driving bars.

In Figure 118, some important known and measured parameters of the members of driving mechanism are shown. First of all, operational voltage and maximum rotational speed of the electric motor is provided by the manufacturer. The motor can reach maximum rotational speed of 400 rev/min under the operation voltage of 24 V DC. However motor power and torque values are not known. The efficiency of the electric motor is assumed as 85 percent since the DC motors are designed to be over 75 percent efficient in general [26]. The pinion gear shown as number 2 has 20 teeth. The number of tooth of its mating gear indicated by the part 3 is counted as 61. The gear referred as 4 is mounted on the same shaft with the gear 3 and its number of tooth is 14. The teeth numbers of gears 5, 6 and 7 are counted as 58, 15 and 40, respectively. Gears 8 and 9 which are the driving pinions both have 16 teeth and the module of these gears is calculated as 5.5 since the pitch diameters are measured as 88 mm. The efficiency of all spur gear mates are assumed as 98 percent [28].

Finally, it is measured that the throwing stroke of the machine is 170 mm and the switching is performed in 8 seconds including the locking and unlocking. This basically describes the motion of the driving bars indicated as components 10 and 11. The efficiency for the rack and pinion gear mates are also assumed as 0.98 similar to spur gear mates.

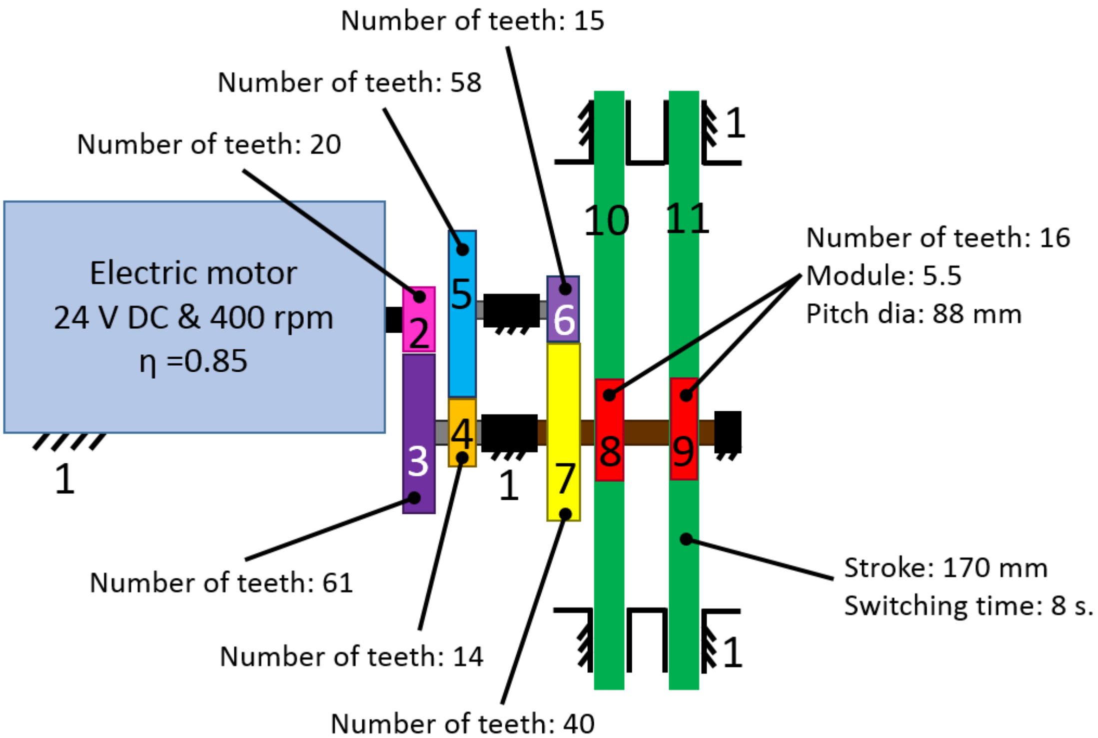


Figure 118 Known and measured parameters of the driving mechanism

Before going into details of analysis of the driving mechanism, free body diagrams of the machine elements 8, 9, 10 and 11 are drawn and the required dimensions are measured on the machine. Since the rack and pinion gear mate formed by components 8 and 10 are exactly the same as that of components 9 and 11, only one free body diagram is drawn for each driving pinion and driving bar. These free body diagrams will help to do force analysis and also to transfer the motion parameters to other components of the machine. Figure 119 presents the driving bar and its pinion gear mate from the side.

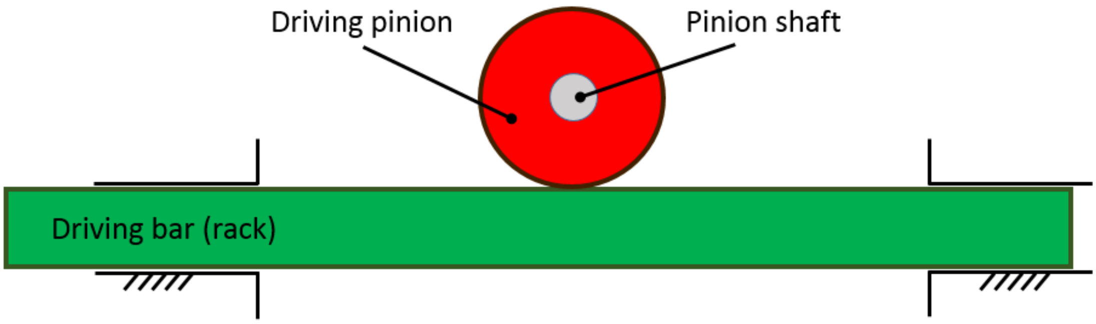


Figure 119 One of the rack and pinion gear mates from side view

Figure 120 shows the free body diagram of gear 8 representing one of the driving pinions. Pitch diameter of the gear is measured as 88 mm. T8 represents the torque applied on the shaft that the gear is installed on it and w8 shows the rotational speed of the driving pinion. F108 indicates the reaction force of driving bar 10 on the contact point. This force has an inclination due to the gear profile and it can be split into its radial and tangential components. F108_t shows the tangential component of the force F108 while F108_r is showing the radial one. The pressure angle Φ is shown between the force F108 and its tangential component F108_t. Its numerical value is assumed as 20 degrees for a standard gear profile in this analysis. The shaft that the driving pinion is mounted on is described by the letter c. The force created on this shaft is shown as Fc8 and it also has the radial and tangential components similar to F108. Radial component of Fc8 is represented as Fc8_r and the tangential component is described as Fc8_t.

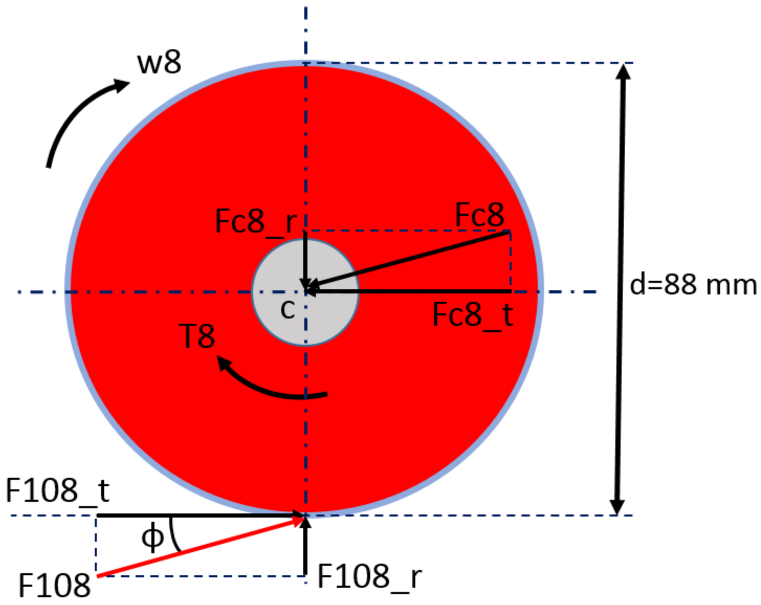


Figure 120 Free body diagram of the gear 8

Figure 121 presents the free body diagram of part 10 representing one of the driving bars of the machine. The height of the driving bar is shown by d1 and measured as 40 mm. The driving bar moves linearly into a slide having the length of d4=200 mm and the gear 8 contacts with that driving bar at the middle of the slide. The contact point of the gear 8 is approximately 6 mm below the upper surface of the driving bar 10 due to the gear profile and this distance is described as d2. The force applied by the gear 8 on the driving bar 10 is indicated as F810 and it has the same pressure angle Φ like on the gear 8. The components of this force along the motion direction and perpendicular to motion direction are shown as F810_t and F810_r, respectively. Reaction force of point blades on the driving bar is represented as F_o. These forces create a moment on the driving bar 10. This moment and radial component of F810 are balanced with the reaction force created by the ground. The point of application of this reaction force 'Fy110' can be in or out of the slide depending on the length of the slide. If the distance "x" shown in Figure 121 is shorter than the distance 'd3', the reaction force is in the slide. Otherwise the point of application is out of the slide therefore it is the resultant of physical contact forces. However these details are not included in this study because the reaction forces are not important and friction forces are ignored.

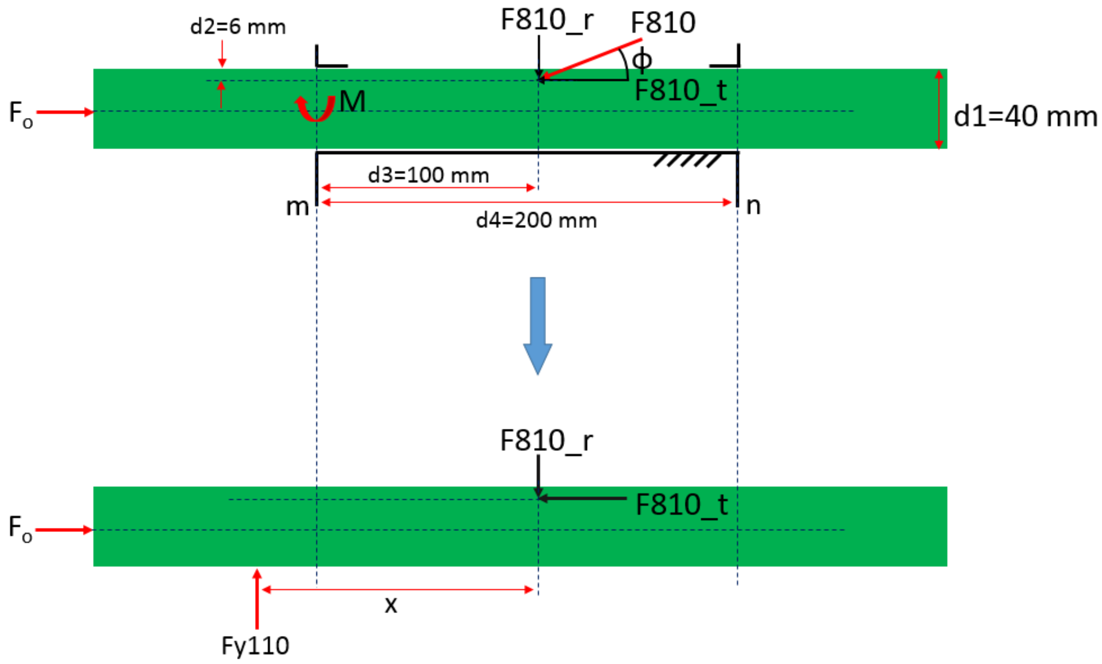


Figure 121 Free body diagram of component 10

In order to start the motion and force analyzes of the driving mechanism, it is needed to know the rotational speed and the torque of the motor shaft. Although operational voltage and maximum rotational speed produced by the motor are provided by the manufacturer, neither the current drawn by the motor nor applied torque are provided. However it is learned that the maximum current which can be drawn by the motor is 12 amperes. This information is obtained from the signal chiefs who worked on this type of point machine at TCDD in the past. Similarly, the information about throwing force of the machine that can be adjusted between 1960 and 2950 Newtons is also shared by them. Moreover throwing distance and switching time of the machine are the known parameters. Therefore it is possible to come back to the input motion of the electric motor by using the parameters of transmission components between the driving bars and the electric motor.

It is important to decide the motion characteristics of the driving bar. It moves 170 mm in 8 seconds but the velocity profile is not known. It is directly related with the motor characteristics. DC electric motors typically have the power curve presented in Figure

122 [29], [30]. In the first region, the motor power linearly increases with the rotational speed. After a certain speed, the motor provides almost constant power like in the second region. It is assumed that the motor of this point machine operates in the first region closer to the second region since the motor torque is constant at its maximum value in this region. The torque reduces with the increasing rotational speed of the motor after the end of first region. Therefore it is a reasonable approach to have maximum torque with the acceptable power below its maximum.

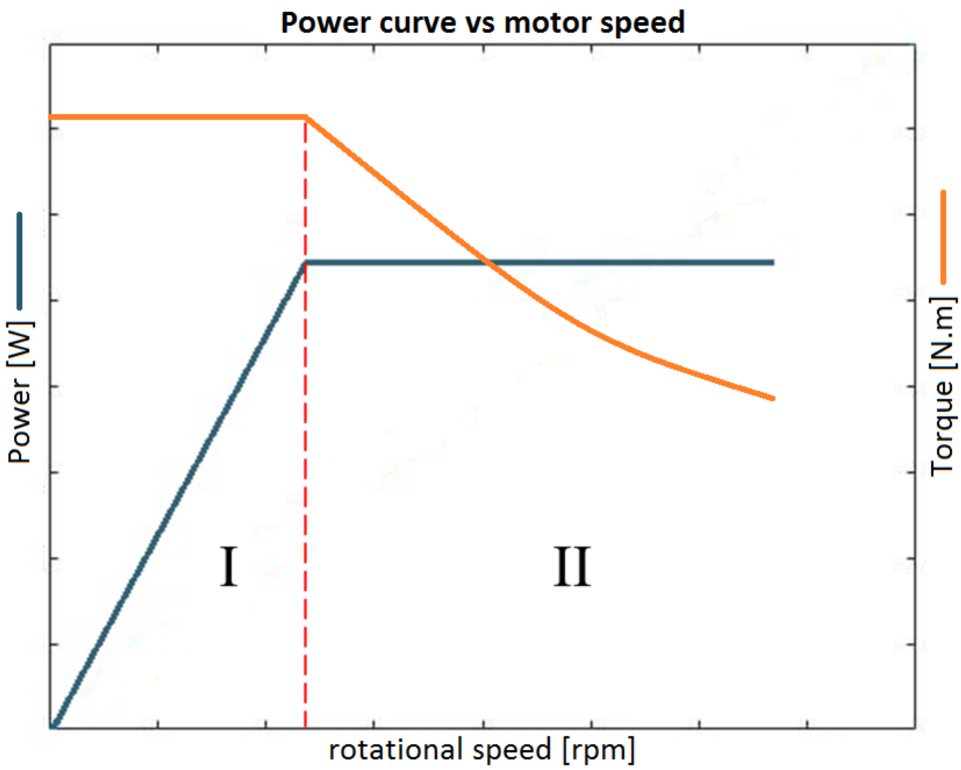


Figure 122 Typical power curve of a DC electric motor

For the motion of the driving bar, it would be a reasonable approach to assume a linear velocity profile at the very beginning of the operation and a constant velocity profile during remaining of the operation. The velocity starts from zero at time equals to zero seconds and increases with a constant acceleration until the velocity stabilizes. Then the driving bar moves with a constant speed until the end of throwing motion. The assumed velocity profile of the driving bar during its throwing motion is presented in

Figure 123. Although the real velocity profile can slightly be different from this assumption, it is an adequate approach and easy to solve.

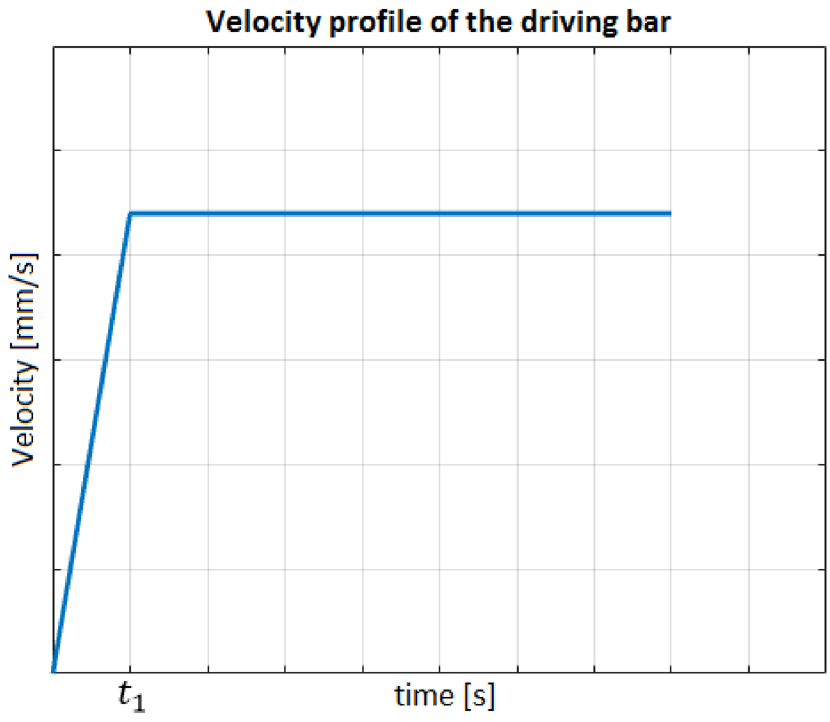


Figure 123 Assumed velocity profile of the driving bar during its throwing motion

The equation of the velocity curve can basically be described as a linear function:

$$V = a * t; \quad for\ 0 < t \leq t_1$$
$$V = a * t_1; \quad for\ t_1 < t < 8 \tag{3-17}$$

The area under the velocity versus time curve gives the displacement of the driving bar and shall be equal to 170 mm. In order to calculate the area under the curve, it is needed to integrate the equation with respect to time.

$$\int V = \int a * t + \int a * t_1 \tag{3-18}$$

$$\int V = \left.\frac{\mathrm{a} * t^2}{2}\right|_0^{t_1} + a * t_1 * t|_{t_1}^{8} \tag{3-19}$$

The time t_1 when the velocity of the driving bar stabilizes is assumed to be 0.5 seconds. The numerical value of the area can be calculated by evaluating the equation (3-19) over the switching time.

$$\int_{t=0}^{t=8} V = \frac{a * 0.5^2}{2} + a * 1 * (8 - 0.5) = 170 \tag{3-20}$$

By solving the equation (3-20), a can be found as 22.3 mm/s^2. Therefore, rewriting the equation (3-17), velocity profile of the driving bar can be obtained as following:

$$\begin{gathered} V = 22.3 * t; \quad for\ 0 < t \leq 0.5 \\ V = 11.15; \quad for\ 0.5 < t < 8 \end{gathered} \tag{3-21}$$

After finding the equation (3-21), assumed velocity profile of the driving bars can be numerically plotted shown in Figure 124.

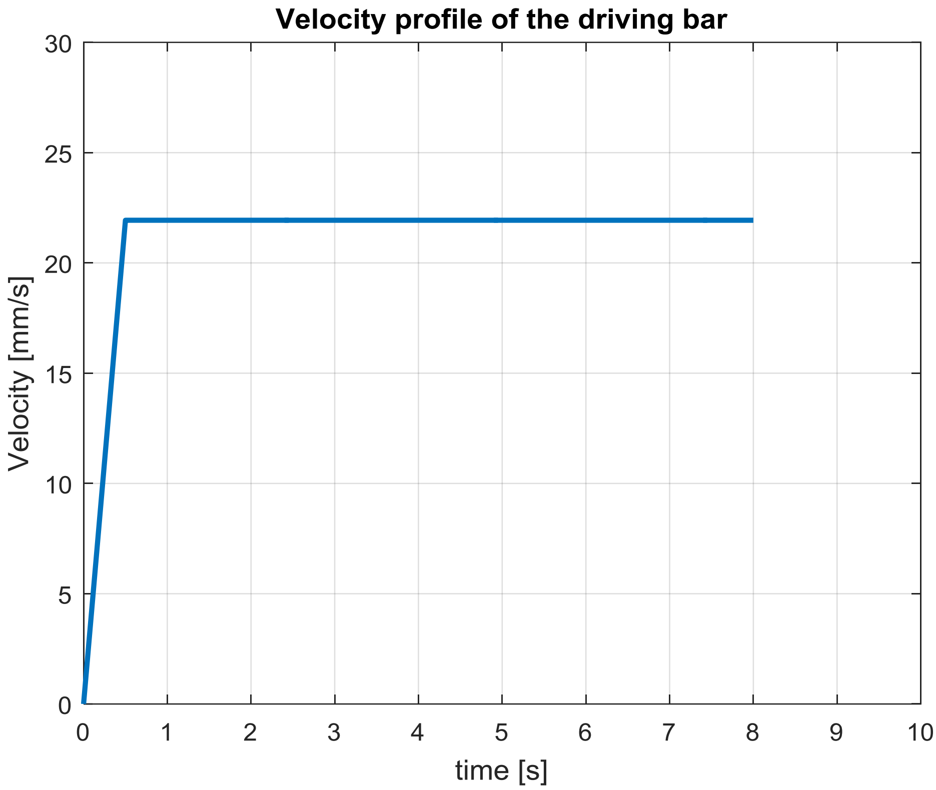


Figure 124 Velocity profile of the driving bar

Rotational speed of the electric motor can be found by knowing the motion characteristics of the driving bars. The method is to come back from the velocity of driving bar to the rotational speed of the electric motor by using the transmission components in between. A Matlab code presented in Appendix C.4 is written to analyze the motion characteristics of the electric motor and Figure 125 shows the change of motor speed during the operation time of the machine. The motor speed described by "w2" in the Matlab code increases with a constant acceleration of 33.6 rad/s^2 up to 160 rev/min and then is kept as constant at that speed during the throwing motion of the driving bar.

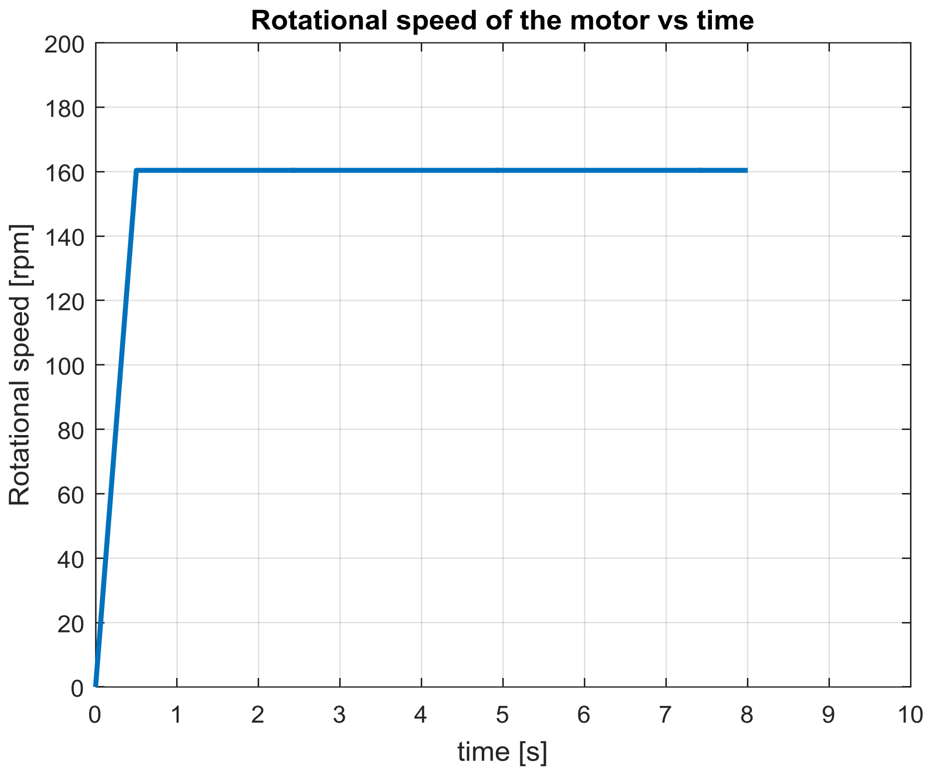


Figure 125 Motor speed during the operation of the machine

Figure 126 shows the supply power change of the motor with respect to rotational speed of the motor. The power supplied from the motor linearly increases up to 96 W during the operation of the machine.

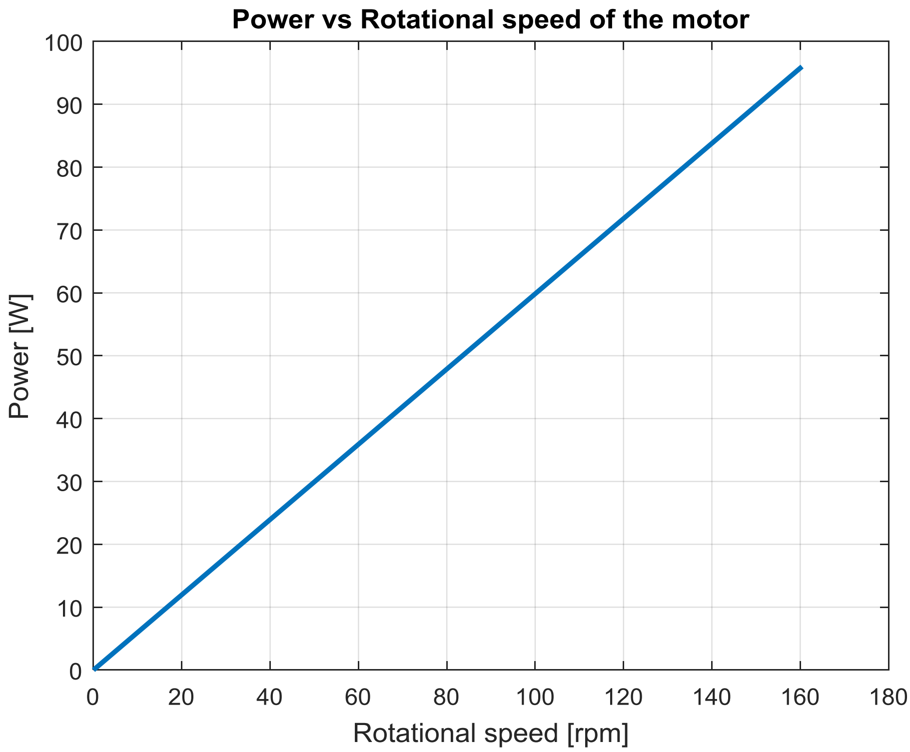


Figure 126 Power curve of the electric motor with respect to rotational speed

The torque applied by the motor indicated by "T2" can also be calculated by knowing the supply power and the rotational speed. Figure 127 presents the torque curve of the motor in its operational time interval. The motor provides constant torque of 5.14 N.m as expected because the slope of the linearly increasing power curve presented in Figure 126 gives the torque applied by the motor.

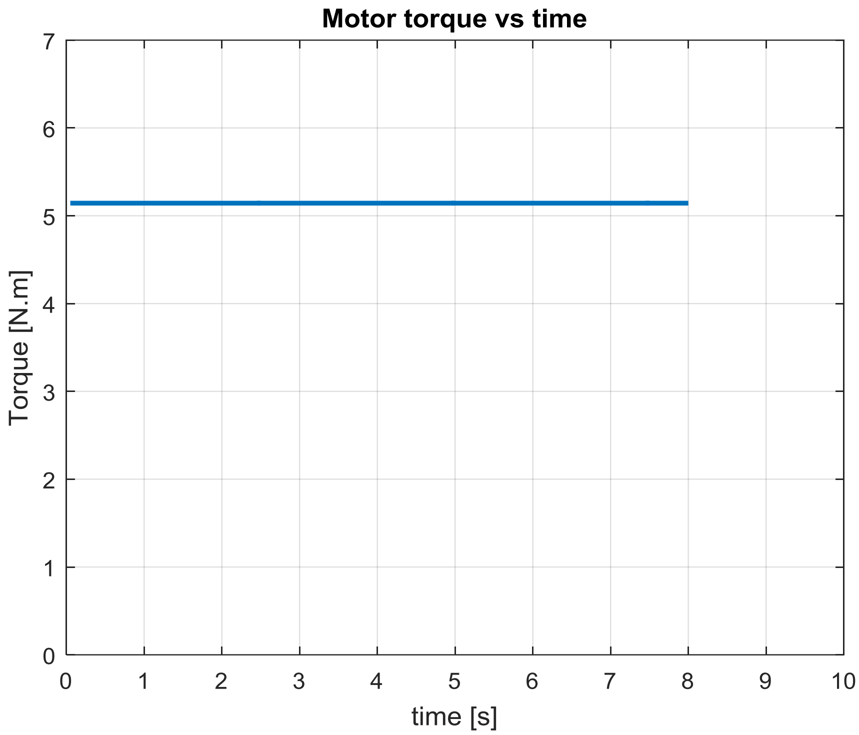


Figure 127 Motor torque during the operation of the machine

The constant torque provided by the electric motor is transferred to the last gear of the gear train which is represented by 7. The torque created on the gear 7 is identified as "T7" and its numerical value is found as 163 N.m by the help of Matlab code. On the other hand, it is known that the throwing force of the driving bars is adjustable between 1960 and 2950 N. When the frictional forces on the slides of driving bars are considered, it is obvious that the force transferred to the driving bars by the driving pinions (gears 8 and 9) is higher than these values. These frictional forces are measured by using a force measurement device. This measurement is repeated at least ten times in order to be sure that the measurements are consistent. Figure 128 shows a photograph taken during one of this measurements. The frictional force at the linear slide was measured as 80 N at average while the driving bar is moving. The maximum force is measured as 95 N at average and it is observed at the impending motion of driving bar.

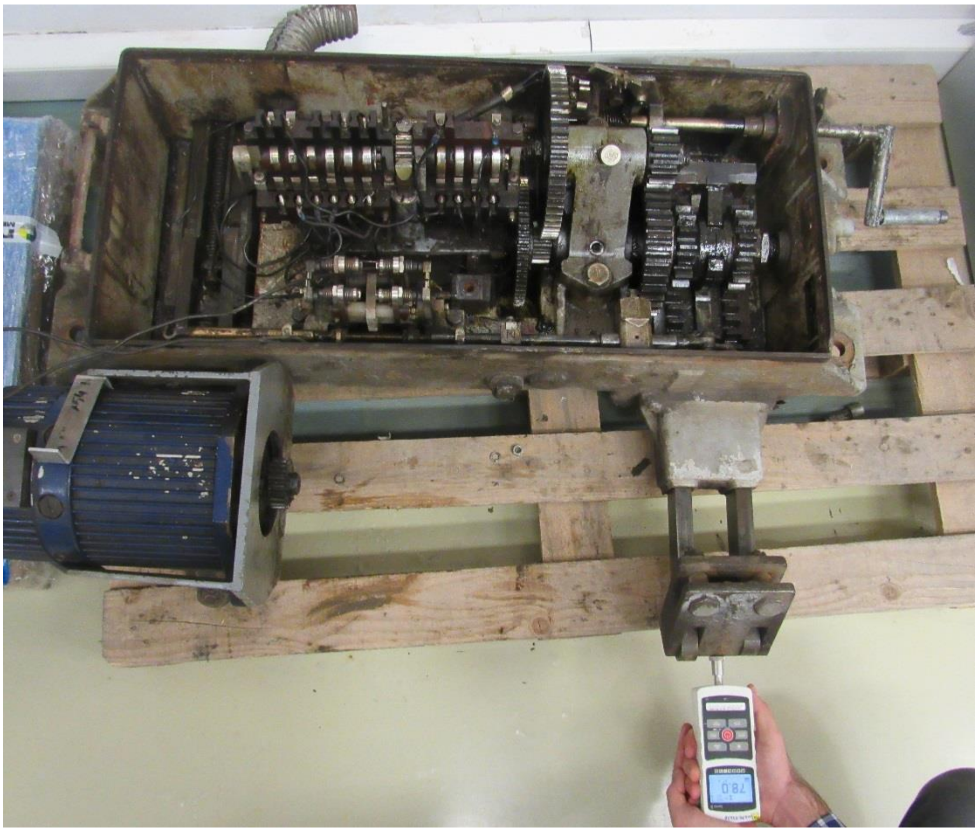


Figure 128 Force measurement at the linear slide of point machine D

When the frictional forces are taken into account, the force applied on the driving bars by the driving pinions along the operation direction “F810_t” is basically found between 2040 and 3030 N. The torque on each driving pinion is calculated between 85 and 125 N.m accordingly by considering the pitch diameters and adjustable throwing force.

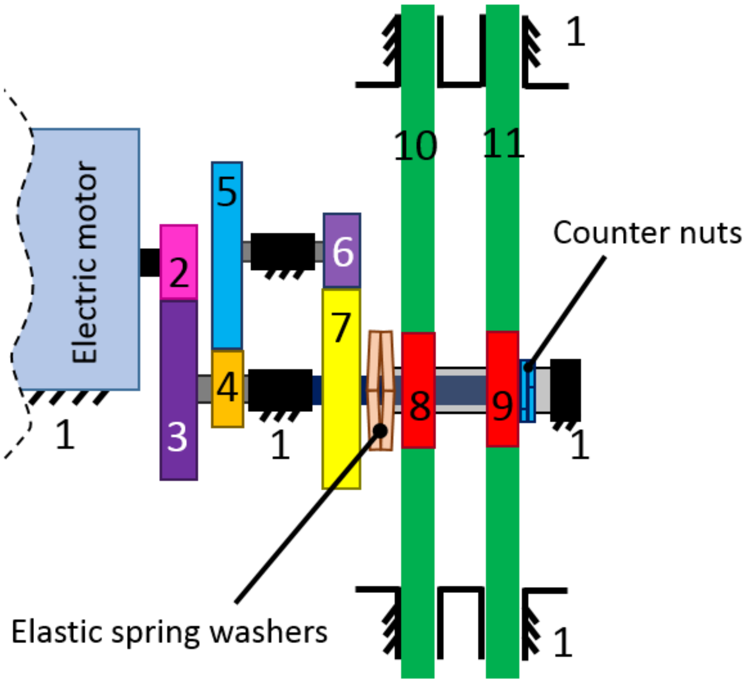


Figure 129 Schematic representation of elastic spring washers (clutch)

The torque on gear 7 is transferred to the driving pinions 8 and 9 by the help of elastic spring washers which act like a clutch illustrated in Figure 129. Until the throwing distance is completely proceeded, the gears 8 and 9 rotate together with the gear 7 thanks to elastic washers. When the driving bars complete their strokes, the rotation of driving pinions naturally stops. However the gear 7 continues to rotate for the locking of driving bars. While one part of the elastic spring washer on the same shaft with the driving pinions is stationary, the counterpart of the washer on the same shaft with the gear 7 slides on the other by exceeding the frictional resistance between them. It can be concluded that some of the torque produced on the gear 7 are lost on the friction clutch while the drive is being transmitted to the driving pinions. The torque lost in the friction clutch is adjustable by the counter nuts and between 38 and 78 N.m. Therefore throwing force of the machine can be adjusted by changing the friction on the clutch by means of counter nuts although the torque produced by the motor is constant.

When the machine completes throwing of the point blades and the engagement occurs with the stock rail, a locking mechanism is activated automatically at these positions.

The locking mechanism essentially locks the two driving bars which are mechanically connected to point blades. In this way the motion of the point blades is prevented and the point is locked. Main components of the locking mechanism are schematically illustrated in Figure 130. The schematic is drawn from the side view but the driving bars are represented, in order to be more clear and understandable, on top of each other even though they are back to back. There is a rotary lock positioned between the two driving pinions and it is directly driven by the gear 7 which is the last gear of gear train. The only connection between rotary lock and driving pinions is the clutch formed by elastic springs. The knob on the rotary lock is the principal part of locking. There is also a teetering arm located under the rotary lock and it can freely rotate about a fixed point on the casing. However it is directly and continuously in contact with the rotary lock all the time. It changes the direction of current feeding the motor by the help of an auxiliary lever at the end of throwing motion.

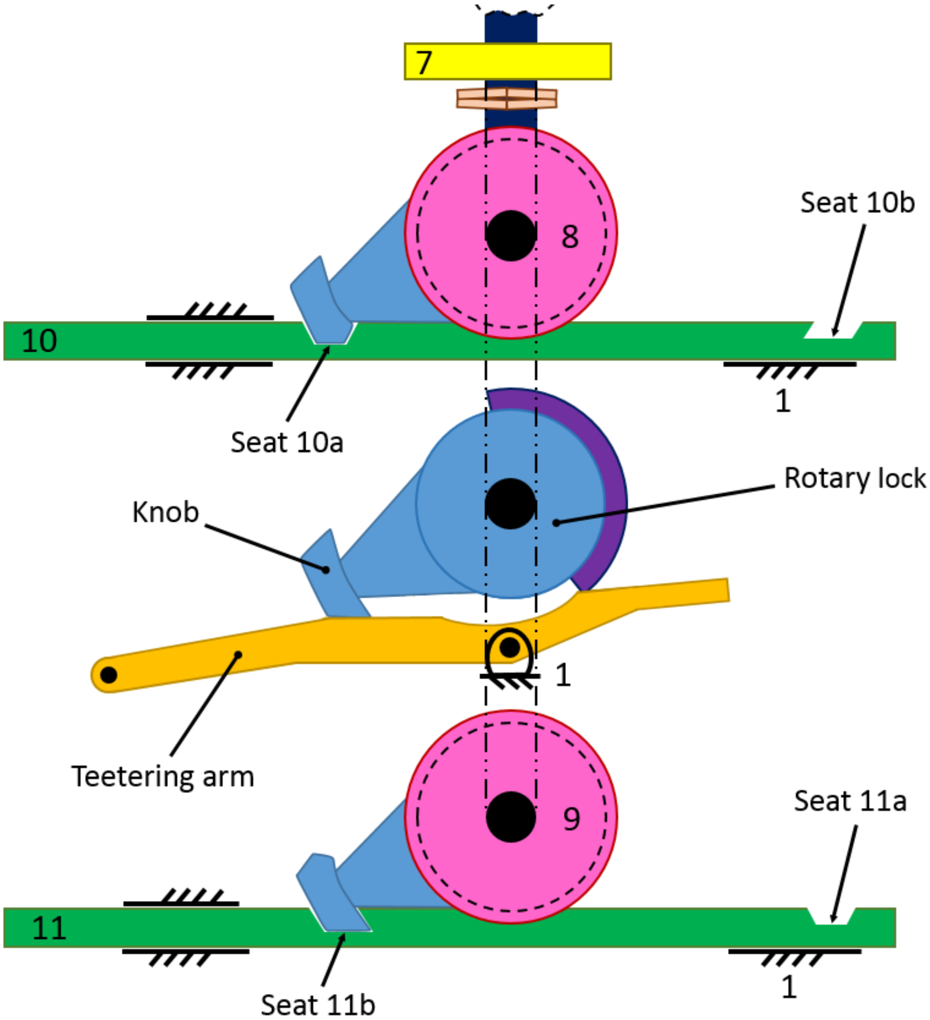


Figure 130 Representative schematic model of locking mechanism together with the driving mechanism from side view

When the throwing distance is completely proceeded, the rotary lock continues to rotate and the knob on it gets into the seats of driving bars. There are two types of seats on the driving bars. The knob on the rotary lock goes into ‘a’ type seat of one driving bar and ‘b’ type seat of the other driving bar at the same time. The locking of the driving bars is guaranteed geometrically by the ‘b’ type seats at each position of the machine. On the other hand ‘a’ type seats are useful only for the trailable version of the machine. Geometrical constraint between the locking knob and ‘b’ type seat is illustrated in Figure 131.

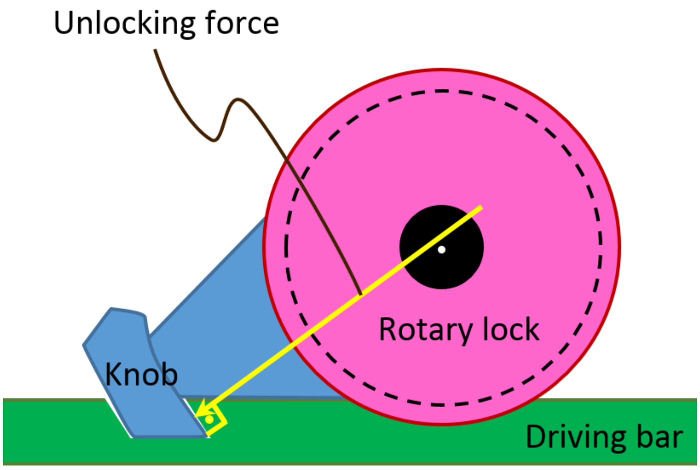


Figure 131 Geometrical constraint for the locking of driving bars

The force coming from the point blades in the unlocking direction acts perpendicularly on the inner surface of knob if the frictional forces are neglected. The line of action of this unlocking force shown in Figure 131 passes over the center of rotary lock. Therefore this force cannot create a moment to take the knob out from its seat. Indeed it forces the knob to stay in that seat since it creates a moment about the center of rotary lock in the locking direction. The same logic is valid at both locked position of the machine.

There is a current conductor and a stabilizer inside the machine and they are represented in Figure 132. Both are operated with the movement of absorbing rod. When the machine is locked, the knob hits the teetering arm to activate the absorbing rod. In this manner, one of the two switches of current conductor is taken apart from its mate when the machine is locked and the current in the supply circuit is directed to rotate the motor in the reverse direction. Apart from the locked positions, however, the two switches of current conductor are in contact with their mates thanks to pre-tensioned spring that is mounted between that switches. This means that the machine is not locked and could be somewhere in between end positions. This also allows the dispatcher to rotate the motor in any direction on both closed circuits of the current conductor. Moreover the stabilizer working with the movement of absorbing rod obstructs the undesirable movements caused by shakes and vibrations that come from the train crossings. It is simply activated by a pre-compressed spring and the protruding tip is inserted into small seats on the absorbing rod when the machine is in locked positions.

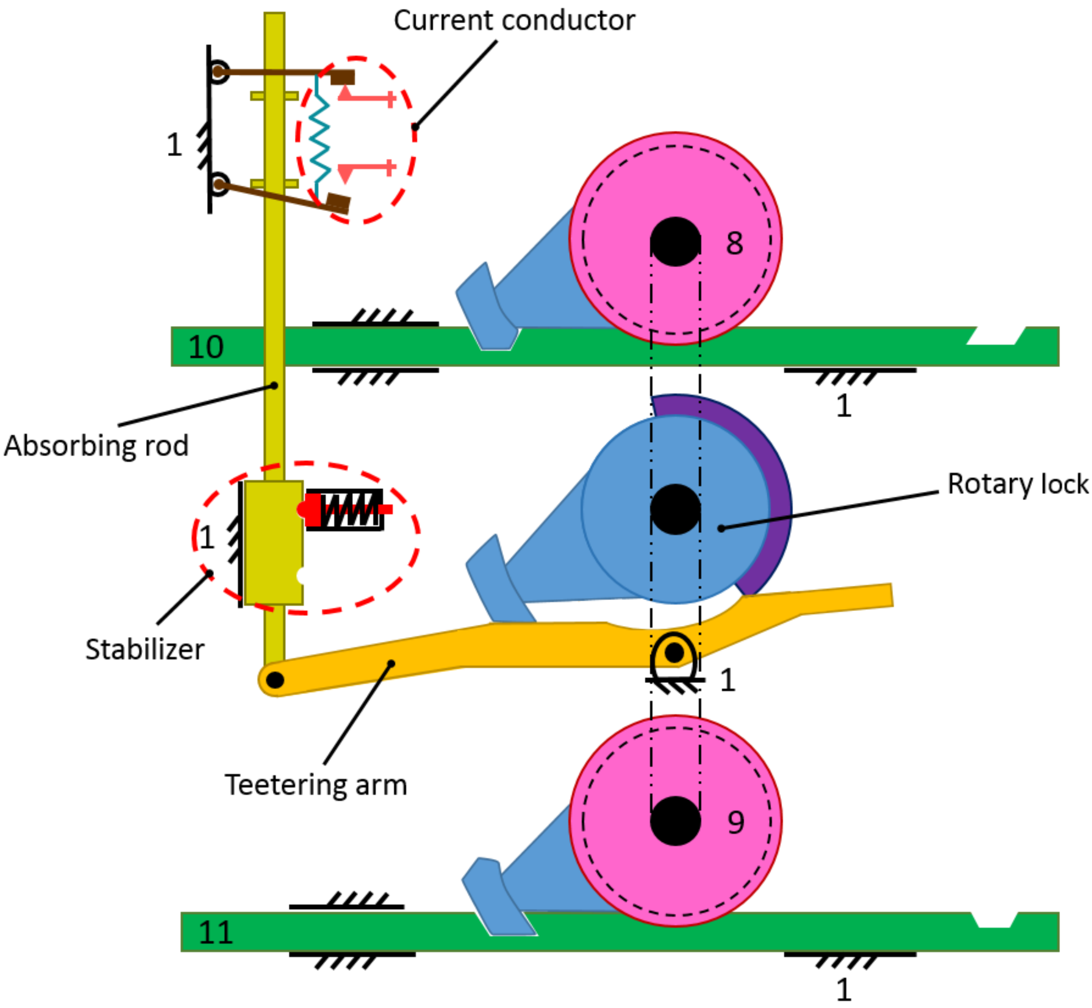


Figure 132 Schematic representation of current conductor and stabilizer

As described at the beginning of this chapter, there are two detector bars having rectangular cross sections to check the correct position of the point blades one by one. One of them is mechanically connected to tip of the near point blade and the other one is connected to tip of the distant point blade by the help of mechanical linkages. When the blades of the point come to one of the end positions and the engagement occurs with the stock rail, a locking mechanism is activated necessarily at these positions.

Indeed the locking mechanism prevents the movement of only one detector bar which is mechanically connected to the closed point blade at each position. The reason why there are two detector bars is to control both of the point blades independently. Since the two detector bars follow the motion of point blades and they are in connection with each other, the detection mechanism works only when both of the point blades are in the desired position.

The two detector bars and the main components of the detection mechanism is shown in Figure 133. There are two threaded rods installed in a molded part which is fixed on the casing of the machine and they are positioned above the detector bars one by one. There is also a connection gear mounted between the threaded rods to ensure that they work at the same time but in the opposite direction. There is also a spring installed between the detector bars providing their connection.

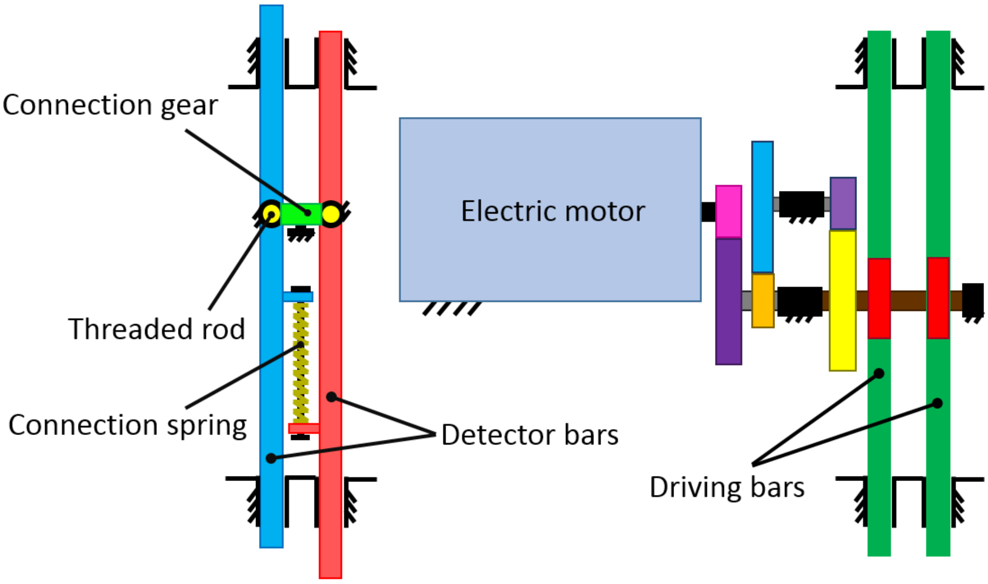


Figure 133 Representative schematic model of detection mechanism together with the driving mechanism from top view

Figure 134 shows any position other than the locked position of the detection mechanism. The schematic is drawn from the side view but the detector bars are represented, in order to be more clear and understandable, on top of each other even though they are back to back. While the link 12 and 13 are representing the detector bars, threaded rods on top of them are numbered 14 and 15, respectively. The detector bar shown as link 13 is connected to close point blade while the other one is connected to distant point blade. The connection gear mounted between the threaded rods is shown as link number 16. The detector bars are connected to tip of the point blades such that the connection spring between the detector bars is always in compression. While the point machine is being operated, the detector bars follow the point blades by keeping the compression in the spring. During that period, the bottom sides of the threaded rods slide on the flat surfaces of the detector bars. Since there is no level change of the link 14 and 15, the connection gear shown as link 16 is not exposed to any rotation. In addition, there are also two compression springs between the threaded rods and ground. During the operation of the machine, these springs are functionless.

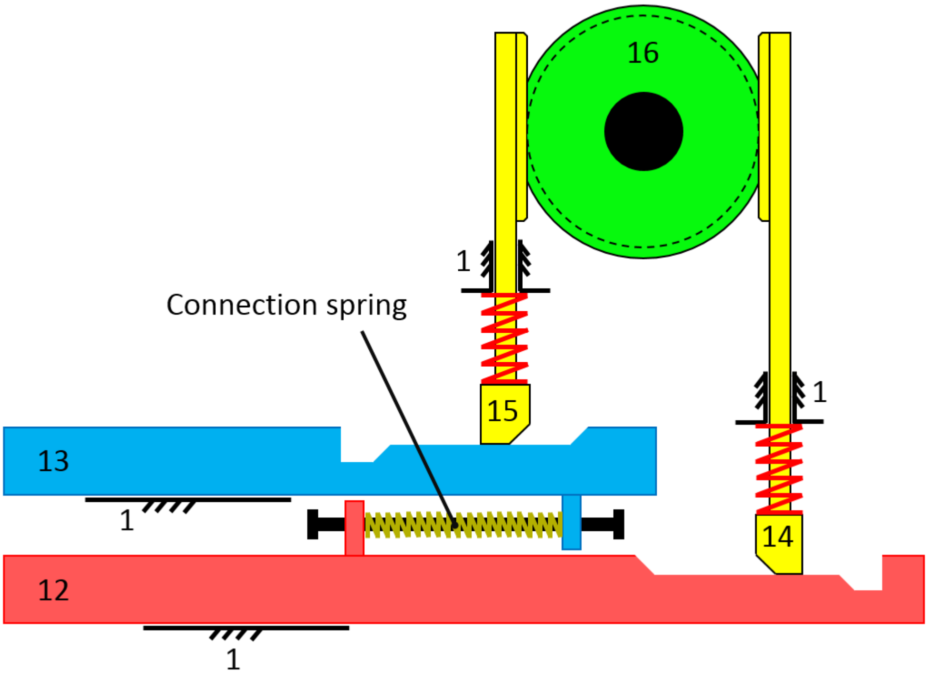


Figure 134 Schematic representation of the detection mechanism

Each detector bar has its own inclined seat on it to activate vertical movement of the threaded rods in coordination. When the machine completes its operation, meaning that the point blades come to one of its end positions, one of the threaded rods goes up and the other one goes down by sliding the inclined surfaces. These vertical movements of the threaded rods occur dependently since they work in coordination with the connection gear on top. Figure 135 shows the locked position of the detection mechanism at the one of end positions of the machine.

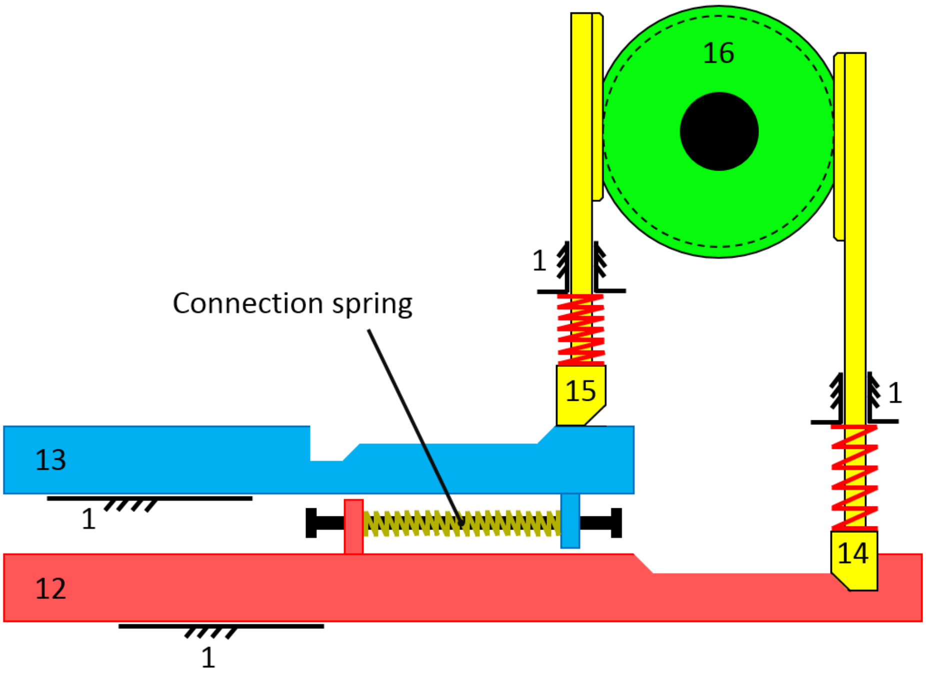


Figure 135 Schematic representation of locked position of the detection mechanism

Since the link 12 is connected to the distant point blade and that blade is engaged with the stock rail for the position shown in Figure 135, this detection bar is locked. At that position of the machine, the compression spring around the link 15 is even more compressed. In the case of a failure of connection between the link 13 and the close point blade, the link 13 is forced to move by the compressed connection spring between the link 12 and link 13. Then the threaded rod shown as link 15 is pushed down by the compressed spring around it and link 14 goes up with the rotation of link 16. This case is reported as a failure to the dispatcher by the commutators installed at the same shaft with link 16. Similar scenario is valid for the other end position of the machine. At that time, the detection bar shown as link 13 is locked and the compression spring around the link 14 is more compressed. If a failure happens between the link 12 and the distant point blade, the link 12 is forced to move by the compressed connection spring between the link 12 and link 13. Then the threaded rod shown as link 14 is pushed down by the compressed spring around it and link 15 goes up with the rotation of link 16. This case is again reported to the dispatcher as a failure.

Since the distance between the knob seats on the driving bars and the length of inclined notches on the detector bars are constant, the stroke of the machine could not be adjusted. Therefore this point machine can only be used on the points having an arrangement clearance of 170 mm.

There are ten semi-ring type electrical commutators formed by two groups. First group contains six commutators installed on the same shaft and they are operated by the absorbing rod. Schematic representation of commutators is shown in Figure 136. Since they are positioned on the same shaft back to back, only one of them is visible from that view. They electrically inspect the position of rotary lock by touching the two opposing switches at the same time. This means that they complete the circuit to generate the related signal when they connect the opposing switches. If they are numbered from front to back respectively, the first and sixth commutators are reserved as spare parts. The others are positioned in different angles so each of them detects different positions of the rotary lock. For example, the fourth commutator connects its opposing switches when the machine is locked in its normal position. Similarly the third one checks the locking of the machine in its reverse position. On the other hand, the second and fifth commutators detect that the driving bars are close to be locked in normal or reverse position of the machine, respectively. Hereby a signal is generated for the dispatcher to know that the point blades are close to their final positions but the machine is not locked yet. If the point machine stays at that position for any reason such as stone or ice jam, the dispatcher knows the position of the machine. Then he operates the machine in the opposite direction and tries to arrange it for the desired position again.

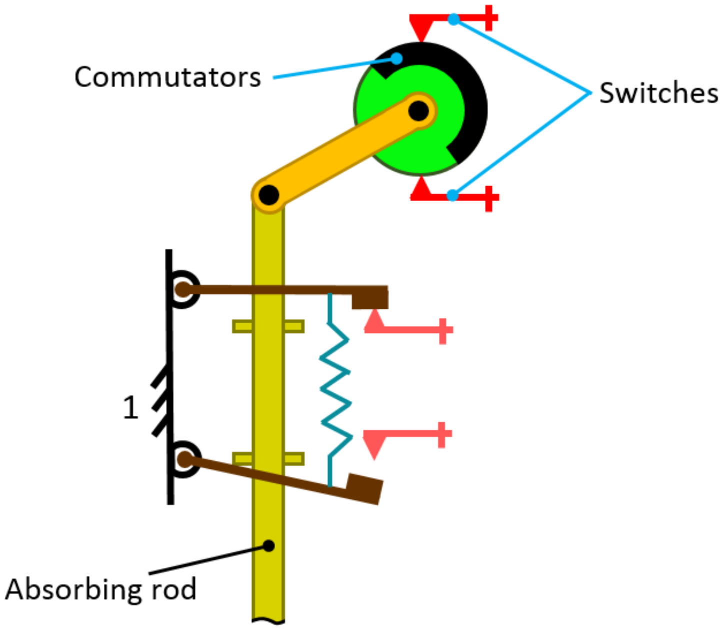


Figure 136 Schematic representation of position commutators operated by the absorbing rod

The second group includes four commutators installed in tandem arrangement at the same shaft with the connection gear (link 16) and operated by the threaded rods on the detector bars. Schematic representation of these commutators is presented in Figure 137. Since they are positioned at the same shaft back to back, only one of them is visible from that view. These commutators are essentially used to control the positions of point blades from the tips whether they are at the desired position or not. Inspection method is completely same as the first group. If they are numbered from front to back side in the order, third and second commutators detect the tip of closed point blade such that it is engaged to the stock rail with a two millimeter tolerance in normal or reverse positions, respectively. The fourth and first commutators, on the other hand, supply information about the position of closed point blades when they are at a distance of four millimeter or further away from the stock rail.

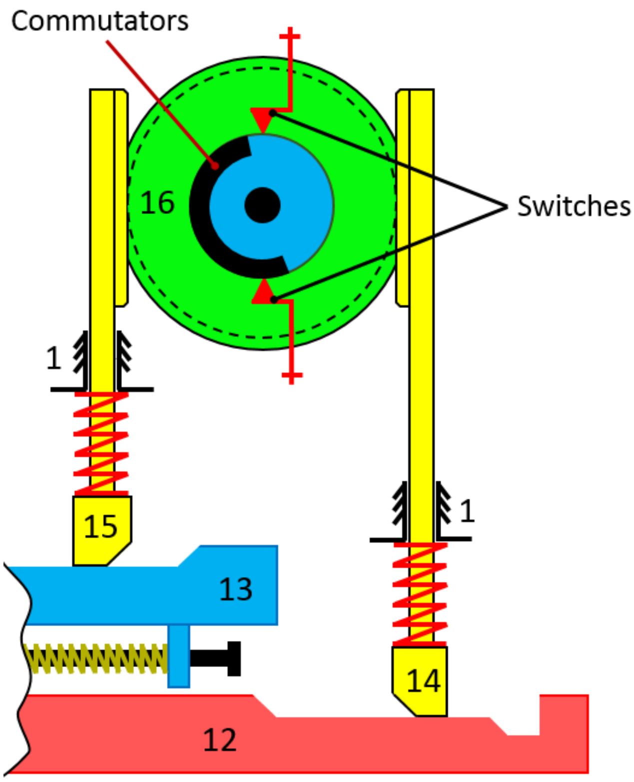


Figure 137 Schematic representation of commutators controlling the tips of point blades

The first and second group of commutators are in series connection. Therefore both locking of driving bars and positions of the point blades are inspected simultaneously to make sure that the point is arranged accurately and reliably.

Wire break, oxidation or arching may cause contact problems in the switches and there is no kind of method to check these problems. When the throwing of the machine is completed, a governing signal is generated to inform the control center. If the governing signal is not received although the operation command is sent to the point machine, it is understood that there is a problem about the operation. The reason of the problem may be the electric motor, locking mechanism, contact switches or other components inside the machine. In this case, in-situ examination is required to understand the reason of failure.

This point machine can also be operated with a manual hand crank. Manual operation is needed during the adjustments in the installation period or in the case of power failure. There is also a safety cut out switch that is activated when the hand crank is used. Figure 138 illustrates the manual operation assembly and energy cut-off switch with a schematic representation.

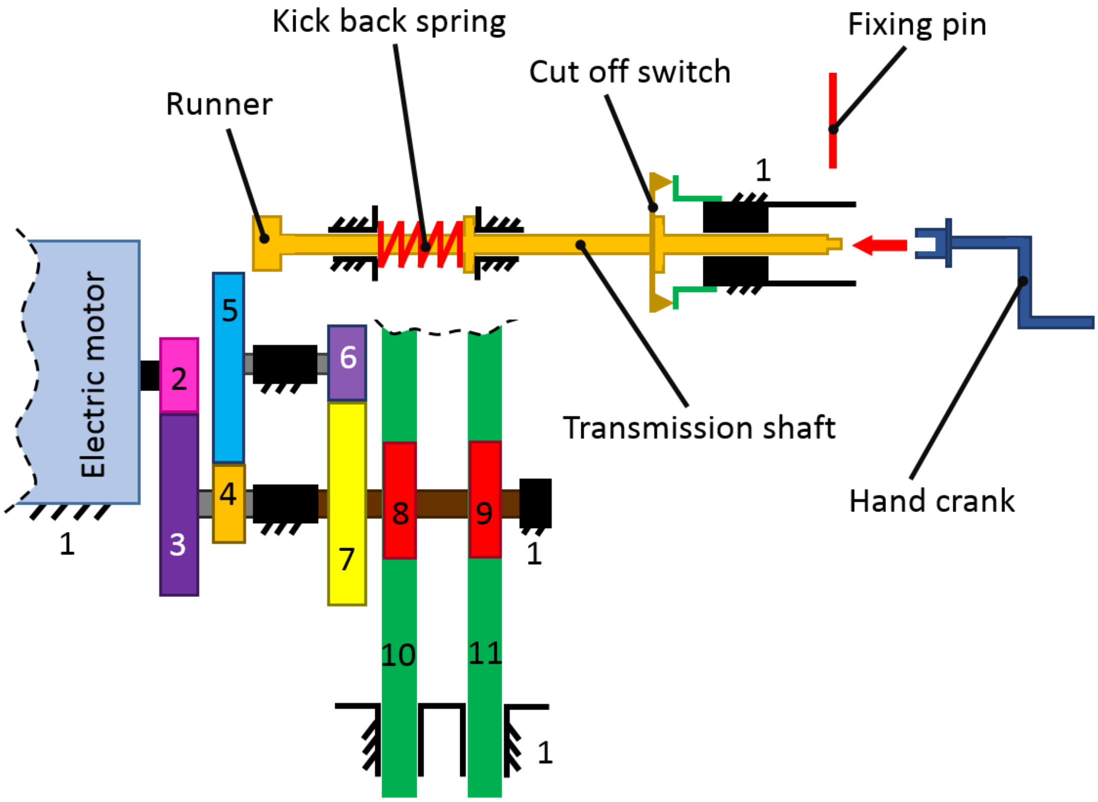


Figure 138 Schematic representation of manual operation assembly

When the machine is required to operate manually for any reason, the hand crank is inserted to the transmission shaft shown in Figure 138. There is a small gear called as runner on the opposite end of transmission shaft to transfer the rotation of hand crank to gear 5. In this manner, rotation of gear pairs are provided by means of hand crank instead of electric motor. There is also a conductive material mounted on the transmission shaft and it works as a contact switch. It allows that the motor is powered on during the normal operation of the machine. On the other hand, supply energy of the motor is cut off when the hand crank is inserted by pushing the transmission shaft as shown in Figure 139. Fixing pin is used to oppose repulsive force of kick back spring. In this way the runner is mated with gear 5 and the machine is operated manually in a safe manner.

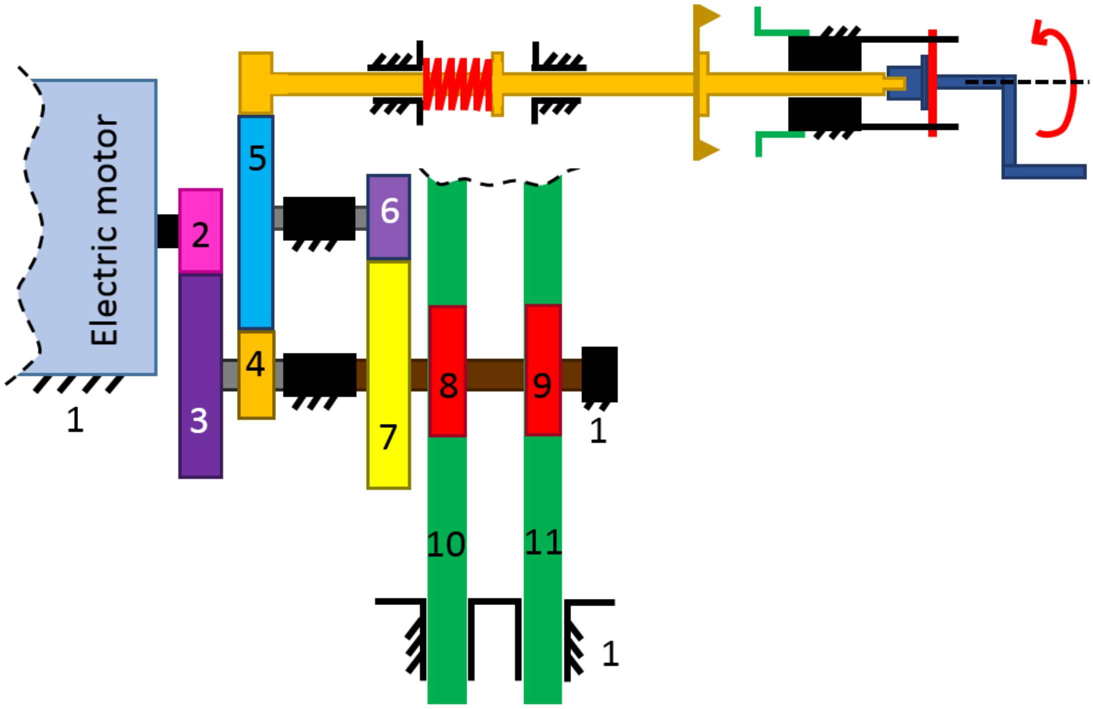


Figure 139 Schematic representation of use of hand crank

CHAPTER 4

COMPARISON OF INVESTIGATED RAILWAY POINT MACHINES

In Chapter 2, some of the contemporary point machines commercially available in the railway market and their specifications were examined. Twelve different types of five different brands are included in this study even though there are other commercial types and brands of point machines in the market. Information about these machines are limited to what is supplied in their leaflet.

In Chapter 3, four different railway point machines which were borrowed from TCDD were investigated in terms of mainly constructional aspects. Although the investigations are performed in the borrowing order, chronological order (oldest first) of manufacture and use is as follows:

1. Point Machine D
2. Point Machine B
3. Point Machine C
4. Point Machine A

4.1 TYPE OF POWER

To begin with, point machines B and D are electro-mechanical point machines whereas A and C are electro-hydraulic. Additionally, when the point machines in the market which are included in this study are considered, it can easily be noted that over 50%

are electro-hydraulic point machines. One of the reasons of using electro-hydraulic powered machines may be high pressures obtained from the hydraulic fluid. High pressures may bring high forces depending on the hydraulic actuators for the throwing of point blades. The other reason of preferring the electro-hydraulic drive mechanisms can be modular construction of hydraulic units inside the machines. To explain, throwing time and force may easily be arranged by changing only the hydraulic pumps because the technical specifications of pumps such as flow rate and operating pressures directly affect the throwing time and force. Including a relief valve in the hydraulic unit may also be an advantage to adjust the system pressure, in case the point may be stuck due to stone or ice. Other than these, the most important advantage of using electro-hydraulic powered point machines could be splitting the machines into two individual units. These individual units can be called as motor unit and drive unit. The point machine may contain either one motor unit and one drive unit or one motor unit with multiple drive units. Unistar HR, Easydrive-i and Hy-Drive are the examples of these type of point machines. They have external hydraulic power packs installed next to track and drive units mostly installed in the center of rails. Multiple drive units with different throwing strokes are preferred at the long turnouts of high speed rail lines. Multiple drive units are operated by single motor unit which is controlled by central command signal. Driving, locking and detection mechanisms are usually contained in a single enclosure in this type of point machines. Hydraulic fluid is pumped from the external hydraulic power pack to the drive unit with flexible hydraulic hoses. This enables the machines to be installed in narrow spaces like metro lines and tunnels. The hydraulic motor unit can even be mounted on the wall or placed horizontally in some cases.

When the chronological order of investigated point machines and literature studies are taken into account, it can easily be concluded that electro-hydraulic powered point machines have become popular in recent years because of these advantages mentioned above.

4.2 CASING MATERIALS AND WEIGHTS

All types of point machines investigated in this study have molded casings containing their electrical and mechanical components. It makes sense to use the method of casting for the manufacturers from the cost-effectiveness point of view. While steel is preferred for casting of casings most of the time, aluminum has also been started to use as a casing material of point machines in recent years. Although the casing materials of all point machines in the market are not presented in their brochures and specification sheets, it is known that most of them are made of cast steel. The casings of investigated point machines B, C and D are manufactured from cast steel even though the casing of point machine A is manufactured from cast aluminum. It is clear that the use of aluminum, especially in the parts which do not make power transmission and which are non-structural parts, results in lighter machines compared to the use of steel. The weights of investigated point machines were not scaled in this study, but the weights of machines in the market are between 95 and 240 kg. The chief of High Speed Train Signalization Department at TCDD, Asım Karagöz, point out the importance of weight of these machines. According to Mr. Karagöz, the point machine should able to be replaced with a new one by only two, at most three, maintenance staff without using any lifting equipment. He says that sometimes it is required to replace the faulty point machines with a new one in a very short time and carrying the lifting equipment near to faulty machine can take some time. Therefore maintenance staff likes the lighter point machines from the view of carrying and installing.

4.3 NUMBER OF DRIVING AND DETECTOR RODS

Basically, throwing of the point blades are performed by the driving rods of the point machines. While some of the point machines have two driving rods, some of those have only a single driving rod. The machines having one driving rod are used as non-trailable most of the time. On the other hand, having two driving rods allow the machines to be used as trailable since they enable each point blade driven separately by the machine. Nevertheless, the MCEM91T point machine is suitable to be used as trailable machine by means of its trailing disc even though it has a single driving rod. When the machines investigated in this study are considered, point machines A and B have single driving rod but the machines C and D have two driving rods. It is obvious that the point machines A and B are non-trailable machines. However there is no doubt that the point machine C is a trailable machine. In spite of having two driving rods, the point machine D is not a trailable machine. The reason is that both driving rods are operated by the driving pinions installed on the very same shaft. In fact they are simultaneously driven by the same input so the motion of driving rods is dependent on each other. In addition, the two driving rods are connected with an external part outside the casing of the machine and they are compelled to move together. As a consequence of that the point machine D is used as a non-trailable machine. Despite of all these, it can also be used as a trailable machine if the group of driving pinions and rotary lock is changed with a new one allowing the driving rods to be driven independently by keeping all remaining parts as the same.

The number of detector bars are always two for all of researched and investigated point machines if the detection function is performed inside the machine. The main reason is to detect the positions of each point blade individually. In some rare applications, external detectors are installed at the tips of the point blades for the detection of desired positions of point blades. The point machines do not have any detector bars for those type of applications. The MCEM91 and MCEM91T point machines are two examples. These machines do not have detector bars since the external detectors are used to check the end positions of the point blades.

The shapes of the driving and detector rods depend on the design of point machines. Some of them are designed as having rectangular cross sections while others are circular. The shape of driving and detector bars of point machines B and D is rectangular whereas machine C has the rods with circular cross sections. Unlike them, the point machine A has a driving bar with a rectangular cross section and detector rods are circular. These do not matter for the purpose of use but engineer Erdinç Çeliker, who is working more than 20 years at the Signalization Department at TCDD, says that slag accumulation on the circular rods are relatively less than that on the rectangular bars. All in all, this may affect the friction forces at the linear slides and the maintenance intervals to clean the machines.

4.4 ELECTRIC MOTORS AND POWER UNITS

Electro-mechanical point machines include electric motors to generate the rotational input motion. When the point machines available in the market are examined, it can be said that they have electric motors mostly operated with the standard voltage values such as 24 V DC, 110 V DC, 220 V AC, 380 V AC and 750 V DC. Some point machine manufacturers offer configurable machines in terms of electric motors. They provide alternative solutions depending on the required voltage by the railway operators. In spite of the current values drawn by these motors change with the operating voltages and resistive loads of point blades, it can be generalized that the maximum starting currents are in between 6 and 12 A and the rated operating currents are between 1.5 and 4 A as an order of magnitude.

When the point machines investigated in this study are taken into account, the motor of point machine B is not installed directly inside of the main casing. It is enclosed by an external casing and positioned from the side of main enclosure of the machine. In contrast, the electric motor of machine D is directly mounted inside the machine casing. While the motor of machine B draws 6.2 A at the beginning of the operation under the potential of 110 V DC, the motor of machine D is operated with the voltage of 24 V DC and it draws 12 A as the starting current. One of the disadvantages of point machine D caused by its electric motor operated by such a low voltage is asserted by Mr. Çeliker. He says that, rated current drawn by the machine D is in between 1.5 and 2 times of rated current drawn by the machine B. Although the current drawn by the machine D is higher than that of machine B, as a result of low operating voltage, the throwing force generated by point machine D is relatively lower than that of other point machines used by TCDD. This can be explained by comparing the output powers of these motors during the operations. While the motor of machine B provides a power of 220 W at a speed of about 1200 rev/min, the motor of machine D provides a power of about 96 W at a speed of 160 rev/min. Although the output power of motor B is higher than twice of that of motor D, the torque produced by the motor B is lower than that of motor D. The reason is that the motor B operates at a much higher speed than motor D.

Unlike the electro-mechanical machines, electro-hydraulic powered point machines A and C have hydraulic power units. Both power packs of the machines contain electric motors having similar power. The electric motor of the point machine A has the maximum power of 700 W while the motor of point machine C has the maximum power of 750 W. The motor of the machine A can be operated with the mono-phase voltage of 220 V or three-phase 380 V and draws the current of 4 A under the potential of 220 V and 2.3 A under 380 V. However the motor of machine C can only be operated with the potential of 220 V and draws the current of 5.7 A under that potential. The motor of machine A produces rotational speed of 930 rev/min while the motor of machine C produces the speed of 890 rev/min. Even though there are some small differences between the motors of the electro-hydraulic machines, both electric motors have a dustproof enclosure with the ingress protection rating of IP 54.

Regarding the operating voltages, Mr. Karagöz expressed his opinions by considering the whole railway lines established by TCDD. He says that mono-phase voltage of 220 V is easily available for most of the railway points in Turkey. At some points where the voltage of 380 V is not available, it is required to use a converter to get the three-phase voltage of 380 V from the single phase AC catenary for the operation of point machines and this results in a costly installation. Therefore, the point machines operated with mono-phase voltage is preferred by TCDD compared to the machines which are operated under the voltage of 380 V.

When the installations of hydraulic power packs inside the machines are considered, hydraulic power pack of the machine A has a compact structure such that a hydraulic block is located in front of the electric motor. This hydraulic block consists of a reversible radial piston pump, an oil tank, check valves and relief valves. The electric motor is connected to this block with a flexible coupling to drive the pump for the generation of pressure. On the other hand, hydraulic unit of the machine C is not as compact as the other one. The electric motor and reversible radial piston pump are mounted on one side and a hydraulic block including an oil tank, check valves and relief valves is positioned on the other side of the casing. Oil transfer between the pump and hydraulic block is provided with the help of three aluminum pipes. The pump is directly driven by the electric motor with the aid of a flexible coupling to generate the pressure similar to that of machine A. Mustafa Ercan, who is deputy director of service from Ankara 2nd Regional Directorate at TCDD, and Mr. Karagöz have an agreement on the disadvantages of hydraulic power packs and other hydraulic equipment such as leakage of hydraulic fluid from the seals and air accumulation inside the hydraulic closed loop.

4.5 POWER TRANSMISSIONS

Power transmission elements are completely different in electro-hydraulic and electro-mechanical point machines. Electro-hydraulic machines use hydraulic cylinders to produce work by using the pressurized fluid yet electro-mechanical machines use gears and other mechanical components to transmit the power. For example, there are two hydraulic cylinders fed from the hydraulic block inside the machine A. The hydraulic fluid inside the cylinders can be pressurized up to 110 bars with a flow rate of 1.5 cm^3/rev. Likewise, there are two hydraulic cylinders which are fed by the hydraulic fluid pressurized up to 110 bars with a flow rate of 1.7 cm^3/rev inside the machine C. In both point machines A and C, the cylinders are fed through aluminum pipes from the hydraulic blocks. On the other hand, transmission of the motor power and motion are provided mostly by the gear pairs in electro-mechanical point machines. To illustrate, a closed gearbox is used in front of the motor and it changes the direction of shaft motion of the motor by 90 degrees in the machine B. A spur gear mate, in addition, is used after the gearbox. Similarly, a gear train is installed in front of the motor inside the machine D. Although the transmissions are achieved in a similar way, the motor of machine B is connected to the gearbox with a flexible coupling while the motor of machine D has a direct mating with the first gear of gear train.

4.6 DRIVING MECHANISMS AND PROMINENT FEATURES

At the end of power transmission, there are different driving mechanisms for different point machines. These mechanisms perform the driving of the point blades which is principally one of the main functions of point machines. In the electro-hydraulic point machines, the force and movement of the hydraulic cylinders are transferred to the driving bars. For example, this transfer is achieved by a rotating disc in point machine A. The force generated by the hydraulic fluid inside the cylinders is decreased but the linear stroke is increased by the rotating disc for the driving bar. An important thing is that the rotating disc allows to adjust the stroke of the driving bar. In a similar way, the force applied by the driving rods and the throwing distance are provided by the hydraulic cylinders in point machine C. However there is no force reduction or increase in the stroke during the transmission from cylinders to driving bars. The force and the stroke applied by the pistons are directly transferred to the driving rods. It should be emphasized that the driving mechanism of machine C allows driving rods to move independently. The driving mechanisms are completely different in electro-mechanical point machines compared to electro-hydraulics. Since the gear pairs are mostly used for the power transmission in these types of machines, throwing of the driving bars are basically achieved by rack and pinion type of gear mates in both point machines B and D. Despite of using same type of driving mechanisms, there is a basic difference between them. The machine B contains only one driving bar, which is actually the rack, and a pinion gear, which is driving it. In contrast, the machine D has two driving bars and two pinions. Nevertheless, the two driving bars move together since the driving pinions are installed at the same shaft and driven together. In point machine D, unlike machine B, there is also a friction clutch for the transmission of torque between rotary lock and driving pinions. The clutch is used to adjust the throwing force of the driving bars.

There are some prominent features of driving mechanisms for different types of point machines. Trailability, adjustable throwing strokes and forces can be considered as advantageous properties of the machines. Although the design principles of the contemporary point machines in the market are not shared in their leaflets, it is known that some point machines have the property of trailability and some are offered with the adjustable stroke or force. Both trailable and non-trailable versions of most of the point machines in the market are proposed by the manufacturers according to the requirements of railway operators. For example, Unistar CSV 24 is a trailable point machine with the adjustable throwing stroke, force and time. Similarly, L710H can be configured as trailable or non-trailable on request. Moreover, it has the property of adjustable throwing force. The investigated point machines in this study have also some precious features based on their driving mechanisms. To begin with, point machine A has an adjustable stroke. This means that it can be used at the points having different rail clearance between 87 mm and 285 mm. Design of the driving mechanism allows technicians to adjust the stroke of the machine in the workshop. Moreover, adjustment of the stroke does not affect the throwing time meaning that the throwing time is constant and independent from the stroke. Adjustable throwing stroke can make it favorable for the use of the same machine in the points having different rail clearances. This type of point machines are also preferred at the high speed railway points since the length of the point blades are relatively long with respect to conventional ones and more than one point machine have to be used in a distributed manner along those points with different clearances. Mr. Karagöz emphasizes that the adjustable stroke makes this machine very useful at the high speed railway points especially having large radius and long point blades. At that kind of points, it is required to use more than one point machine and operate them at the same time since the lengths of point blades are relatively long with respect to that of conventional railway points. In order to use more than one point machine, they have to have different throwing strokes because the clearance between the point blades and the stock rails changes from the heel to tip of the blades. Use of point machine A at the high speed railway points brings the advantage of using one type of machine at a time and they complete their operation at the same time independent from their strokes. Secondly, driving mechanism of the point machine C makes it a trailable machine. Trailable machines enable the trains to pass the points which are not arranged for their routes. During the trailing movement, firstly the point blade which is not engaged with the stock rail is forced to move by the wheels. Since the two driving rods can move independently, the related rod connected to the open point blade is moved when the trailing force of the machine, calculated roughly between 8 and 10 kN in Chapter 3, is exceeded. Then the two driving rods start to move together through the trailing direction and allow the train to pass through the point in the trailing direction. If it is compared with the trailing forces of other point machines in the market, S 700 K can be trailed by the force of 9 kN. On the other hand, trailing force of MCEM91T point machine changes depending on operational stroke. For example, trailing force is 9250 N for the stroke of 220 mm and 10700 N for 160 mm.

Although trailing is not a usual movement over an incorrectly arranged point, the points can sometimes be trailed accidentally or by other reasons. Mr. Ercan states that in some locations such as depots and maneuver loops, it is often convenient to allow the trains to run through the trailing points. Therefore, the point machine C can preferably be established in these locations. In like manner, the machine D has a capability to be used as a trailable point machine although the investigated one in this study is non-trailable. As explained before, the point machine D has two driving bars to operate the point blades one by one. These two driving bars are connected with an external part outside the machine and they are driven with a couple of pinions rotating together. If the external part connecting the driving bars is removed and the group of driving pinions is changed with a new couple that can be driven independently, the point machine D can also be used as a trailable machine at the points where the trailing is allowed. Last but not least, the clutch used for the torque transmission enables to adjust the throwing force of the machine by changing the friction on the clutch by means of counter nuts.

4.7 THROWING TIMES, FORCES AND STROKES

Throwing of the point blades is one of the main functions of point machines. Fundamental parameters of the throwing motion are throwing strokes, times and forces. Analyzes of the motion characteristics of investigated point machines revealed concrete data regarding these parameters. The analysis of machine A shows that the throwing stroke of the machine is adjustable between 87 and 285 mm. Throwing time is calculated as 5 seconds and is not affected by the stroke. Depending on the stroke, throwing force changes between 4500 and 14600 N. Analysis of point machine B is performed by measuring the throwing stroke and knowing the throwing time. The force applied by the driving bar is then calculated as more than 4 kN. Point machine C is analyzed by observing the throwing stroke of 163 mm. Throwing time of the machine is calculated as 4 seconds by using the known and measured parameters such as rotational speed of the motor, applied pressure by the pump, flow rate of the pump, diameter of the hydraulic cylinder. At the end, throwing force is found as 6.7 kN. Finally machine D is investigated in terms of throwing time, stroke and force. It is relatively slow when compared to others. Despite the throwing force applied by the machine D is adjustable between 2 and 3 kN with the aid of friction clutch, it is significantly lower compared to the other machines.

Throwing times and forces directly affects the efficiency of rail traffic and the comfort of turnout operation, respectively. Short throwing times increase the efficiency of rail traffic especially in the fields where a lot of point machines are installed. High throwing forces, on the other hand, increase the comfort of point operations. This can be illustrated with the experiences of Mr. Ercan and Mr. Çeliker. They express their opinions in terms of throwing forces by comparing the point machines A and D. They face with some problems at the points where point machine D is installed because of small stones or a piece of ice jammed between the stock rails and point blades. On the other hand, this problem is decreased to a minimum at the points where point machine A is installed. It is expressed that the force applied by the point machine A could break down the ice most of the time. Need of repeating the throwing operations for any reason also decreases the efficiency of rail traffic.

Furthermore these information are readily available for the point machines in the market most of the time. Some of the products are designed to have distinct characteristics in terms of throwing force, stroke and time. However some point machines in the market can easily be customized depending on requirements of railway operators. The point machines having the capability of adjustable throwing time, stroke and force are also available in the market. It can be generalized that the throwing forces of the machines vary in between 4 and 7 kN. It is not easy to compare the throwing times of the machines since for some machines it also depends on the stroke. Nevertheless it can be said that the throwing strokes are mostly in between 40 and 260 mm, and the throwing times are in between 1.5 and 6 seconds. Fundamental reason of these variances may be the type of application. Whereas some point machines are used at the points of light rail vehicles like tram and metro lines, some are used at the points of freight, conventional and high speed rail lines. The type of points affects directly both throwing force and strokes. Therefore there are many point machines in the market developed according to different requirements. For example, the points on the conventional lines need the point machines having higher forces than that of tram lines. In addition, the points at the high speed rail lines require the machines having longer stroke values compared to other points.

Table 14 summarizes the results of technical data obtained from the investigated point machines and some of other products available in the market.

Table 14 Throwing parameters for the researched and investigated point machines

	Throwing time	Throwing stroke	Throwing force
Point machine A	5 seconds	Adjustable between 87 and 285 mm	Between 4500 and 14600 N, depends on the stroke
Point machine B	4 seconds	160 mm	4140 N
Point machine C	4 seconds	163 mm	6700 N
Point machine D	8 seconds	170 mm	Adjustable between 2000 and 3000 N
S 700 K	5 seconds	150 mm	5500 N
	6 seconds	220 mm	
Unistar CSV 24	0.5–1.5 seconds	Adjustable between 38-120 mm	Adjustable up to 6000 N
Unistar HR	1-5 seconds	Adjustable between 60-163 mm	Adjustable up to 17000 N
Easydrive-i	< 2.5 seconds	Adjustable between 100-160 mm	4000 N
MCEM91	3.5–4.8 seconds	Adjustable between 100-260 mm	4000-10400 N
MCEM91T	3.5–4.8 seconds	Adjustable between 115-260 mm	4000-9000 N
L710H	Can be customized and < 6 seconds	Can be customized for any type of point	Adjustable up to 6000 N
L826H	5 seconds	Adjustable between 80-260 mm	Adjustable between 2000 and 7000 N
P80	5 seconds	150 mm	> 5500 N
Hy-Drive	4-10 seconds, depends on power supply	Factory configurable between 36 and 110 mm	Adjustable up to 10000 N

The friction forces at the joints and other mechanical contacts for all investigated point machines are neglected since there are radial bearings or bushings at the revolute joints and low frictional superficial contacts between the friction surfaces of the links. However the friction forces at the linear bearings between the driving bars and the casings of the machines are measured by using a force measurement device in order to get an idea about the order of magnitude of the friction forces. Although the shapes, materials and installation methods of the driving bars differ from each other, the frictional forces measured at the linear bearings did not show much difference compared to operational forces of the machines. For example, the lowest frictional force measured is 30 N at average for the machine C while the driving bar is moving. On the other hand, the highest force measured at the linear bearings is 80 N at average for the machine D while the driving bar is moving. The minimum and the maximum frictional forces measured at the impending motions of the driving bars are 40 N and 95 N for the machines C and D, respectively. Considering the magnitudes of measured friction forces at the linear slides, it can be concluded that they are quite small compared to throwing forces.

4.8 LOCKING FUNCTIONS

Locking of the point blades at the desired end positions is another main function of the point machines. Most of the locking mechanisms are included in the same casing with the main components like motors, power units and driving mechanisms. On the other hand, some of the point machines are designed such that they have external locking mechanisms operating in coordination with the driving mechanisms. S 700 K and AH950 are the examples of point machines with external locking. In this type of machines, driving is usually performed from the side of track and locking is performed by an external locking mechanism mostly at the center of rails.

This principal function is accomplished by all investigated point machines in different methods internally. First of all, the locking mechanism of the machine A is automatically activated when the point blades come to one of their end positions. The lock prevents the motion of both detector rods and rotating disc. As a consequence of that the locking of both driving bar and detector rods is ensured with the same mechanism. Two locking mechanisms are installed opposite to each other in order to achieve the locking at two final positions of the machine and they work independent from each other. In point machine B, the locking scheme is completely different. The existing position of the driving bar is continuously kept by the help of gearbox. Worm and wheel gear set used in the gearbox provides sufficiently high friction to be self-locking. Thus the driving bar is always locked in any position of the machine when the motor is unpowered. There are also additional components such as locking discs and detector arms to achieve the locking of detector bars. When the machine completes its operation, the locking disc allows the detector arm to get in the recessed sections of the detector bars. In this way, the motion of the point blades connected to detector bars are restricted. Thirdly, the locking of driving and detector rods in machine C is achieved by means of different components. The rocker installed on the throwing block is the main component to lock the driving rods. When the machine completes its stroke, the roller on the rocker is received by the locking recesses which are fixed on the machine casing. Since the motion of throwing block is prevented, the driving rods are locked. The locking of detector rods are achieved with the help of locking bars. Protruding tips of the locking bars are pushed in the seats of detector rods when they are in the desired end positions. Lastly, the locking of point machine D is achieved with different components for the driving and detector bars similar to machine C. One of the driving bars is locked by the rotary lock at each end position. The knob on the rotary lock goes into the seat of driving bars. Since both driving bars are fixed with an external part and they move together, it is sufficient to lock one of the driving bars. The main reason why both of the driving bars are not locked at the same time is that the driving bars move independently of each other in the trailable version of machine D. In that case, the train passing through the trailing point first pushes the driving bar which is not locked and then this driving bar allows the other one to move by releasing the lock. On the other hand, the locking of detector bars is achieved by the threaded rods that are connected to the same gear. They work in coordination with each other by sliding the inclined surfaces on the detector bars. This locking mechanism actually locks the detector bar which is connected to the point blade engaged with the stock rail at each end position of the machine. Second detector bar is free to move and it helps to release the lock of first one when the trains pass through the point by trailing. In summary, locking of driving and detector bars is achieved with the same mechanism in point machine A. Although there is only one locking mechanism to lock the detector bars in machine B, the driving bar is always locked in any position of the machine thanks to worm and wheel gear pair used in the gearbox. In contrast to machine A and B, there are two different locking mechanisms for the driving and detector rods in the machine C. Similarly, locking of the driving and detector bars is achieved by two different mechanisms in machine D.

Mr. Ercan and Mr. Çeliker express their opinions about the locking mechanisms of these machines. They say that the locking of point machine D is clearly observed but the locking of machine B is not obvious since friction locking is applied inside the gearbox. In addition, the safety level of machine D is higher than that of machine B according to them. They state this fact on the basis of their personal experience and the strength of knob on the rotary lock of machine D. On the other hand Mr. Karagöz shared his comments about the locking mechanisms of point machines A and C in terms of adjustment and maintenance activities. He says that checking and adjustment of the locking of machine C are easier compared to that of machine A because the locking of throwing and detector rods is clearly seen when the cover is opened. However, it is not easy to see the gaps on the detector bars of machine A so the adjustment of detector bars is not so easy as machine C.

4.9 ELECTRICAL CONTACTS AND DETECTION FUCTIONS

Detection of the desired end positions of point blades is another critical function of point machines. Detection is always achieved by electrical contact switches and desired positions are always supervised at the tips of point blades. Therefore detector bars are connected to tips of point blades. Electrical contacts used to detect the desired locked positions are obviously activated by the motion of detector bars most of the time. On the other hand point machines, in some applications, do not have detector rods. In this type of applications, detection of the desired locked position of point blades is achieved by either an external independent detector or an external detector with integrated locking. The best example of this type of application is the MCEM91 point machine. It does not have detector bars and the detection is achieved by the external locks with integrated detection inside. In any case, regardless of the method of detection, electrical contact switches are used to generate the detection signal and the control center is informed about whether or not the machine is locked.

When the investigated point machines in this study are considered, they all have several electrical contact switches activated by the detector rods. In point machine A, two contact switches are used and they are normally closed while the machine is in operation. Activation of the switches, in fact opening of the switches, is provided by the locking four-bar mechanisms. Indeed the locking four bar mechanisms are released when the detector rods are in desired end positions. In point machine B, there are twenty contact switches and they are operated in a meaningful way two by two. Two of them are idle and can be used as spare parts. Four contact switches are used to decide the rotational direction of electric motor. Four pairs of switches are assigned for the positive and negative poles of supply voltage of the motor. The remaining four pairs are used for the detection of locked position of the machine. These switch pairs are activated by the locking mechanism of the detector bars. Activation of the switches means that they are closed to generate the related signal. In machine C, two contact switch pairs are installed at the tip of each locking bars. While the machine is in operation, the lower switches in each pair are normally closed and upper switches are kept as open. When the machine is locked, the lower switch contact is broken and upper one is released to close the circuit at the related side. The motion of these switches is directly provided by the physical contact of locking bar. Unlike contact switches of first three machines, there are ten semi-ring type electrical commutators formed by two groups to inspect the locking of point machine D. First group contains six commutators and they are operated by the absorbing rod. Two commutators are reserved as spare parts. Two commutators check the locking of machine at each end position. The remaining two detect that the driving bars are close to be locked in normal or reverse position of the machine. The second group includes four commutators and they are operated by the threaded rods on the detector bars. Two commutators in the second group detect the tip of closed point blade engaged to the stock rail with two millimeter tolerance. The other two give information about the position of closed point blades when they are at a distance of four millimeter or further away from the stock rail. Additionally, first and second group of commutators are in serial connection to inspect both locking of driving bars and positions of the point blades simultaneously and to make sure that the point is arranged accurately and reliably.

If the machines are compared in terms of electrical contact switches, point machine A has the minimum number of switches while the machine B has the maximum among them. The machine A informs the control center whether the machine is locked or not. However the contact switches in machine B are not only used to detect the locking of the machine but also used to decide the rotational direction of the motor by checking the poles of supply voltage of it. Unlike machine A, there are spare contact switches which are ten percent of total number of switches in the machine B. Moreover, an important difference of switches installed in the machine B is that they work in series to generate a meaningful information. In point machine C, similar to machine A, the contact switches generate the signal to inspect only the locking of detector rods. The only difference between the switches of machine A and machine C is that the locking information is generated by opening the related circuit in machine A, but the same signal is sent to the control center by changing the closed circuit position of the switches in machine C. Technically, the type of switches used in machine A is *single pole-single throw* while the type of switches used in machine C is *single pole-double throw*. Finally, the type and working logic of the switches of point machine D are completely different from the others. Two different groups of commutators inspect the locking of driving bars and the final positions of detector bars independently. Then these signals are sent to the control center in series connection. Similar to machine B, some of the commutators are used to detect the positions of driving bars such that they are close to be locked or not. There are also two commutators reserved as spare parts in this machine.

4.10 MANUAL OPERATIONS

Manual operation is a property of all point machines in the market. They need to be operated manually by using a hand crank in case of power failure or for other reasons.

There is no doubt that the manual operations need permission to ensure the safe operation of rail vehicles. A lock is used to prevent the operations without permission.

All investigated point machines included in this study can also be operated manually by using a hand crank. Although the methods of the manual operations are different, there are some kind of electrical switches in all investigated types of point machines to cut off the supply energy of electric motors. These safety cut out switches are activated inevitably when the hand cranks are inserted to the machines. In only point machine C, unlike the others, supply energy is cut off by the operator manually before inserting the hand crank. In fact, the operator is obligated to take this action in order to use the hand crank for the manual operation. Mr. Karagöz explains the working principle of manual operation of point machine C. There are two handles, one of them is used first to cut off the supply energy and then the other one is used to operate the machine manually. In summary, the supply energy is disconnected necessarily for the safe operation when the machines are needed to operate manually. In point machine A, the electric motor is directly driven by rotating its shaft at the back side with the help of a crank. Similarly, the motor shaft is rotated from the side by the help of bevel gear pair in the machine C. In contrast, the electric motors are not directly driven by the hand crank in the machines B and D. In machine B, the gearbox is driven manually by the hand crank. Similar to that, the gear train in the machine D is operated manually. Mr. Çeliker, Mr. Ercan and Mr. Karagöz have the same experience about the manual operations of all these point machines. They all have an agreement on the importance of number of rotation of hand crank. The number of rotation of hand cranks can be very important in the case of lack of energy especially at the depots or at the places where several number of point machines are installed. In this case, the staff has to operate several number of machines one by one and this can be tiring and time consuming. Mr. Çeliker illustrates the difference by comparing the point machine A with the others in terms of number of rotation of hand cranks. According to him, while the machine A completes its operation with 96 rotations of hand crank, others complete their operations less than 20 rotations of hand cranks. For example, this number is 15 for the point machine D. As a result, high number of rotation of hand crank is considered as a disadvantage of point machine A. However a low number of rotation may be an indicator of high torque requirement for hand operation that might be tiring for the person doing manual operation.

4.11 INSTALLATION LAYOUT

Point machines can be categorized according to their installation layouts. They are usually mounted at the center, right or left of the track. Most of the point machines installed at the side of the track are suitable to be used for left- or right-hand layouts without any changes of the machines. Point machines mounted at the center of the tracks are often preferred at the tram lines. Unistar CSV 24 is one example of this application. Although the point machines having a central installation layout are frequently preferred at the tram lines, they are not used at the points of main lines operated by TCDD. Therefore all point machines investigated in this study are suitable to be used for left- or right-hand layouts. These point machines have the capability of installation at both sides of the tracks without any changes of the machines. Furthermore, in some applications which include more than one unit, power unit is installed near the track and drive unit is installed at the center of the track. This type of point machines can easily be installed in narrow spaces like trestles, metro lines and tunnels. The power unit of this type of point machines can be positioned on the wall especially in the tunnel applications. Unistar HR and Hy-Drive can be considered as the examples of this type installation. These are generally preferred for the use at the points of high speed rail lines.

4.12 MAINTENANCE AND REPAIR ACTIVITIES

Maintenance and repair of point machines are one of the important aspects for the railway operators. This has been becoming a challenging competition among the contemporary point machines. Some point machines in the market such as S700 K and Unistar HR are expected not to fail throughout their operational lives since their mean times between failures is over 500 000 hours. Similarly the MCEM91 and MCEM91T point machines have the MTBF values of over 30 years. Although mean time between failures are usually promoted by the manufacturers, mean time to repair is also important as mean time between failures. The mean time to repair of most of the point machines in the market like Switchguard Surelock, Unistar CSV 24, Unistar HR and Hy-Drive is less than 20 minutes. The MCEM91 and MCEM91T point machines have the MTTR values of between 35 and 40 minutes.

When the investigated point machines in this study are considered, it can obviously be said that the components of point machines B and D are easily accessible to maintain or repair. However there are some inaccessible components in the machines A and C since they have compact structures. To confirm, Mr. Çeliker, Mr. Ercan and Mr. Karagöz shared their experience about the maintenance and repair activities of these point machines. They all agree on the easy maintenance and repair of machines B and D since all component are easily accessible without dismantling any other part. If a component inside these machines fails, it can be replaced with a new one even in the field where the machines are established. However machines A and C have complex constructions and this results in inaccessible components inside the machines. Mr. Karagöz says that one faulty machine is mostly replaced with a new one and the faulty one is repaired in the workshop. According to Mr. Ercan and Mr. Çeliker, the maintenance activities of electro-mechanical point machines which are machines B and D include mainly cleaning and greasing of gear pairs and other moving mechanical components. Moreover, adjustments of throwing and detector bars and checking of locking mechanisms take place in the routine controls. On the other hand, Mr. Karagöz explains the maintenance activities of electro-hydraulic point machines which are machines A and C. He says that the maintenance activities include cleaning and greasing of moving mechanical components, air discharge from the hydraulic loop and adding hydraulic oil in the system.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

This study involves comparison of constructional aspects of different railway point machines. This has been accomplished by the investigation of four different point machines borrowed from TCDD. The studies are conducted in three main steps. In the first step, modern point machines which are commercially available in the market and their operational characteristics are researched. In the second step, four different point machines which are currently used at the railways operated by TCDD in Turkey are investigated in detail. In the final step, constructional and operational aspects of both researched and investigated point machines are compared. In this manner, background and guidelines for the development of a novel and domestic point machine are obtained.

At the beginning of the study, research about the points and point machines has been performed to learn working principals and main functions of them. The history of point machines from switch stands to modern point machines has also been reviewed. Then different types of brands of point machines commercially available in the market and their specifications have been examined. Only twelve different types of five different brands are included in this study although there are more types and brands of machines in the market.

Next intermediate step is the detailed investigation of four different point machines that are borrowed from TCDD. It should be noted that although there are more types of point machines used at the railways operated by TCDD in Turkey, the scope of this thesis study is limited to only four point machines. In order to avoid making advertisement or smearing the brand names, the investigated point machines are entitled by the letters like point machine A, point machine B and so on. These machines have been examined in terms of mainly types of power, casing materials, power packs, electric motors, power transmissions, driving mechanisms, throwing times, strokes and forces, locking mechanisms, electrical contacts, detection functions and manual operations within the scope of these investigations. Matlab codes are written to perform position and force analysis of each point machine.

The final step is the comparison of investigated point machines in terms of constructional aspects. Advantages and disadvantages of the machines are introduced based on the investigations. In addition experience of TCDD staff, who are working more than 20 years on the maintenance and signalization services, are also included in this study.

5.2 CONCLUSIONS

The point machines investigated in this study are classified as electro-mechanical and electro-hydraulic powered which are most commonly used in the railway industry. However electro-hydraulic powered point machines have become more popular in recent years. The first reason may be relatively high forces caused by high pressures obtained from the hydraulic fluid. High throwing forces are required at the modern railway points, especially for the high speed rail lines. Furthermore, high throwing forces are crucial for the safe and efficient operations of the points in the case of small stones or piece of ice jammed between the stock rails and point blades. Easily customizable construction may be another reason of popularity. For example, throwing forces, strokes and times can easily be customized by changing the stroke and diameter of the hydraulic actuators. Moreover flow rates and operating pressures of hydraulic pumps have strong effects on the operation characteristics of the machines. Installation of a relief valve in the hydraulic system can be another advantage to adjust the pressure without changing any component inside the machine. The most important advantage of electro-hydraulic point machines could be modular structure, means that splitting the machines into individual units. Modular structure of the machines as discussed in Chapter 4 allows them to be installed in a flexible manner especially at the points of high speed rail lines and at the points in narrow spaces. Popularity of the electro-hydraulic powered point machines can also easily be seen from the market research and chronological order of investigated point machines. Although there are some advantages of electro-hydraulic powered point machines, leakage of hydraulic fluid from the seals and air accumulation inside the system can be considered as the disadvantages of this type of machines.

Use of aluminum for the casing material of the machines has been tried by some of the manufacturers and this obviously results in lighter point machines. Lighter machines are favored by the maintenance staff of the railway operators since carrying and installing activities are easy compared to heavy machines.

Whereas some point machines have two driving rods to throw the point blades, some of those have single driving rod. Most of the time the machines having one driving rod are non-trailable machines. However, having two driving rods enable the machines to be used as trailable since they enable each point blade to move independently. Nevertheless, some point machines having one driving rod are used as trailable machine although two point blades are moved together. When the machines investigated in this study are considered, point machines A and B have single driving rod but the machines C and D have two driving rods. While the point machines A and B are non-trailable machines, the point machine C is a trailable one. The point machine D is not a trailable machine but it can be used as a trailable machine if some components are changed with the suitable ones by keeping all remaining parts as they are.

The number of detector bars are always two for all point machines if the detection is performed inside the machine. The main reason of having two detector bars is to detect the positions of each point blade individually. If the detection is not performed inside the machine but external detectors are used for this function, then the point machines do not have any detector bars in this type of applications.

Electric motors of investigated point machines have been examined to obtain information about their types, operating voltages, powers and current drawn. It should be noted that each motor is operated under different voltages such as 24 V DC, 110 V DC, 220 V AC and 380 V AC. There are some point machines operated with other voltage values in the market. Alternative solutions are sometimes offered by the manufacturers depending on the required voltages. This diversity gives rise to thought about the availability of all these potentials at the infrastructure where the point machines are installed. Although all these machines are operated at the railway points in Turkey, the point machines operated with mono-phase voltage of 220 V AC are preferred by TCDD compared to others. It can be generalized that the maximum motor power of these machines is between 500 W and 1 kW. However rated output power is between 100 W and 400 W while they are being operated. Despite of the current values drawn by the motors change with the operating voltages and resistive loads applied by the point blades, it can be generalized that the maximum starting currents are between 6 and 12 A and the rated operating currents are between 1.5 and 4 A as an order of magnitude.

Power transmissions and driving mechanisms of the point machines have also been analyzed to figure out the driving of point blades which is one of the principal functions of point machines. They are completely different in electro-hydraulic and electro-mechanical point machines. While hydraulic cylinders are used to produce work with the help of pressurized fluid in electro-hydraulic machines, a gearbox or a gear train is mostly used to transmit the motor power in electro-mechanical machines. In electro-mechanical point machines, like machine B and D, rack and pinion gear mates are used to throw the driving bars. On the other hand, the force and linear motion of hydraulic cylinders are transferred to the driving rods directly like in the machine C or indirectly like in the machine A. As a result of these analyzes throwing times, strokes and forces of investigated point machines are obtained and the data are presented in Table 14.

Locking of the point blades at the desired positions is another main function of point machines. It is seen that most of the point machines have internal locking mechanisms. On the other hand, external locking mechanisms can also be used in some applications of point machines. If the external locking is preferred, the locking mechanism is installed usually at the center of the track or just next to the track. Point machines investigated in this study all have internal locking mechanisms and they are examined to understand how they perform this crucial function. In all machines, both driving and detector bars are locked. Generally they are locked by separate mechanisms but exceptionally locking of both driving and detector bars is performed by the same mechanism in point machine A. It should also be noted that the driving bar of machine B is kept locked in any position by using worm and wheel gear set causing sufficiently high friction.

The last principal function of point machines which is detecting the locked positions of point blades has been examined. Although external detectors are rarely used in some applications for the detection of desired locked positions of point blades, there are always two detector bars connected to tips of the point blades to supervise the locked positions if the detection is performed internally. Basically several kinds of electrical contact switches are always used to inform the control center regarding the locking status of the machines. In all point machines, locking information is generated only when both point blades are at the desired position. In some applications, close circuits are opened to generate the detection signal while open circuits are closed in some others.

Prominent features of the point machines have also been investigated during this study. Trailability can be considered as one of these features. Trailable machines, like the point machine C, allow the trains to pass the points even if the points are not arranged for their routes. Most of the trailable point machines have two driving rods to allow motion of each point blade separately. In contrast some point machines having one driving rod can also be used as trailable but the two point blades move together in these applications. Trailable point machines are preferred especially in the depots and maneuver loops. Most of the point machines in the market have trailable and non-trailable versions. Generally the designs of the machines allow them to be configured as a trailable and non-trailable by changing the some components inside them such as point machine D investigated in this study.

The second important property of a point machine is adjustable stroke. This allows the machine to be used at the points having different rail clearances. This type of point machines, like the point machine A, are highly preferred especially at the high speed railway points since the point blades are long and they need to be operated with more than one point machine. Most of the point machines in the market have the property of adjustable stroke. Moreover, adjustable throwing force can be considered as another property of the machines. Throwing forces of some point machines in the market can be adjusted according to operation requirements. The throwing force of point machine D can also be adjusted between 2000 N and 3000 N by using a friction clutch. This property may be useful for the use at the points of high speed rail lines since more than one point machine are used at that points in a distributed manner and the resistive loads are different throughout the point blades.

As a final step, manual operations and installation layouts of the machines have been studied. All point machines can be operated manually by using a hand crank in case of a power failure or for any reason although the methods are different. Manual operations need permission all the time. This prevents tampering with the machines without permission. In addition, there are electrical switches inside the machines to cut off the supply energy of electric motors and they are activated inevitably when the hand cranks are inserted to the machines to ensure the safety of operators.

To conclude, this thesis study has been performed on four different point machines and some of their constructional and operational aspects have been investigated. However other point machines used by TCDD should be examined as a future work to obtain deeper background. Besides more different point machines in the market should also be researched to get the information about competitors. Although the constructional aspects of point machines have been investigated in this study, the scope is limited with casing materials, power packs, electric motors, power transmissions, driving mechanisms, locking mechanisms, electrical contacts, manual operations throwing times, strokes and forces. In addition to these studies locking forces, component materials and installation methods should also be examined in the future to complete the mission of this study.

Considering the motivation of this study, it should be emphasized that using a single type of domestic point machine at the points of both conventional and high speed rail lines and also urban rail lines is very important and beneficial in Turkey. The use of a single type point machine brings several advantages in terms of spare part supply, maintenance and training activities for the railway operators like TCDD and municipalities. Moreover this provides the accumulation and sharing of national knowledge and experience. Depending on the user experience and demands, therefore, improvement of existing point machine and development of new versions and models can be performed in a quick manner.

At the end of this study, depending on the market research and investigations of different point machines, guidelines acquired for the development of a novel and domestic point machine are as follows:

- The throwing time of the machine should be less than 4 seconds up to throwing stroke of 200 mm. It should also be less than 5 seconds for the stroke values greater than 200 mm.
- The throwing force of the machine should be more than 7000 N for each stroke value.
- The throwing stroke of the machine should be adjustable between 80 mm and 260 mm.
- The weight of the machine should be 120 kg at maximum without compromising the reliability and robustness.
- The machine should have versions of trailable and non-trailable.
- The design of the machine should be modular such that it allows converting the non-trailable version to trailable by including additional components or by changing the existing components.
- The machine has to have two detector bars to inspect the positions of each point blade individually.
- The ingress protection rating of the machine should be minimum IP 65 and preferably IP67.
- The machine should be operated with mono-phase voltage of 220 V.
- Operating temperature of the machine should be between -30^{o}C and +70^{o}C.
- The driving and detector bars have to be locked at the desired end positions.
- Retention force of the machine should be at least 30 percent more of the throwing force.
- The locking of the machine should be clearly observed.
- Locked positions of the machine have to be detected and this should be achieved by using electrical contact switches.
- The machine has to be operated manually with a hand crank.
- Manual operation of the machine have to be subjected to permission.
- Supply energy of the machine has to be cut off inevitably when the hand crank is used.
- The machine has to be suitable for the installation of right- and left-hand layout without any change in the machine.

- All components in the machine should be easily accessible as possible without dismantling any other part.
- The machine should be mounted on a pair of sleeper with a suitable mounting brackets.
- The machine should have a compact size such that it should be installed in narrow spaces like trestles and tunnels.

REFERENCES

[1] Turnouts. Retrieved from https://www.railsystem.net/turnouts/

[2] Railroad switch. Retrieved from https://enacademic.com/dic.nsf/enwiki/103192

[3] Turnouts. Retrieved from https://mysite.du.edu/~jcalvert/railway/turnout.htm

[4] Railroad Construction In Kleefskill, NY. Retrieved from https://www.railroad-line.com/forum/topic.asp?TOPIC_ID=27190&whichpage=9

[5] Aldon Company, Inc. Retrieved from https://www.aldonco.com/store/c/207-Easy-throw-Handles.aspx

[6] Tout, N. (Photographer). (2009, July 14). Retrieved from https://upload.wikimedia.org/wikipedia/commons/a/a2/LiecesterAndSwannington02A.jpg

[7] Turner, J.H. Howard. (1977). *The London, Brighton & South Coast Railway*. London, England: B. T. Batsford Ltd.

[8] Tönük, E. (Photographer). (2006, November 18). *Sabuncupınar istasyonunda makaslara (mavi) ve semaforlara (kırmızı) kumanda eden manivelalar* [digital image]. Retrieved from https://users.metu.edu.tr/tonuk/E40003/MekanikSemafor/Sabuncupinar.html

[9] Tönük, E. (Photographer). (2006, November 18). *Makasa kumanda eden ve makası kilitleyen "makas sandığı" adı verilen kutu* [digital image]. Retrieved from https://users.metu.edu.tr/tonuk/E40003/Cevre/Makas.html

[10] Woolley, J. (Photographer). (2007, October 16). *BY225A_1209_Bletchley* [digital image]. Retrieved from https://www.flickr.com/photos/pics-by-john/8061856524/in/photostream/

[11] ETCS. Retrieved from http://uic.org/etcs

[12] Point machines of the 61.1 Metro series. Retrieved from https://www.hanning-kahl.com/products/point-setting-systems/electric-point-machines/point-machines-611-metro-series.html

[13] Siemens AG. (2008). *S 700 K point machine* [Brochure]. Retrieved December 06, 2017, from https://www.mobility.siemens.com/mobility/global/SiteCollectionDocuments/en/rail-solutions/rail-automation/signaling-components/s-700-k-en.pdf

[14] Siemens AG. (2013). *Switchguard surelock points drive system* [Brochure]. Retrieved December 15, 2017, from https://www.mobility.siemens.com/mobility/global/SiteCollectionDocuments/en/rail-solutions/rail-automation/signaling-components/switchguard-surelock-en.pdf

[15] Voestalpine Signaling Zeltweg GmbH. (n.d.). *Switching systems standard AH950* [Brochure]. Retrieved December 08, 2017, from https://www.voestalpine.com/signaling/static/sites/signaling/.downloads/produkte/ah950-weichenantrieb/voestalpine_signaling_ah950_pointmachine_switchmachine.pdf

[16] Voestalpine Signaling Sainerholz GmbH. (n.d.). *Unistar CSV 24 electrical point machine for grooved rail and flat bottom rail turnouts* [Brochure]. Retrieved December 10, 2017, from http://www.voestalpine.com/signaling/static/sites/signaling/.downloads/produkte/unistar-csv24/voestalpine_signaling_unistar_csv24_pointmachine_switchmachine_lightrailtraffic.PDF

[17] Voestalpine Signaling Sainerholz GmbH. (n.d.). *Unistar HR switch machines for railway and mass transit applications* [Brochure]. Retrieved December 11, 2017, from http://www.voestalpine.com/signaling/static/sites/signaling/.downloads/produkte/unistar-hr/voestalpine_signaling_unistar_hr_pointmachine_switchmaschine_settingsystem.pdf

[18] Vossloh Cogifer SA. (n.d.). *Easydrive-i electro-hydraulic point machine* [Brochure]. Retrieved February 07, 2018, from https://www.vossloh.com/01_product_finder/VCO/Signaling-products/R62/02fiche_easydrive-i_en_BD_rev5.pdf

[19] Vossloh Cogifer SA. (n.d.). *MCEM91 point machine* [Brochure]. Retrieved February 08, 2018, from https://www.vossloh.com/01_product_finder/VCO/Signaling-products/MCEM91/05fiche_mcem91_en_BD_rev5.pdf

[20] Vossloh Cogifer SA. (n.d.). *MCEM91T trailable point machine* [Brochure]. Retrieved February 08, 2018, from https://www.vossloh.com/01_product_finder/VCO/Signaling-products/MCEM91T/06fiche_mcem91t_en_BD_rev3.pdf

[21] Thales Transportation Systems GmbH. (2016). *Point machine L710H* [Brochure]. Retrieved February 19, 2018, from https://myproducts-thales.com/brochures-documents/812-leaflet-point-machine-l710h/file

[22] Thales Transportation Systems GmbH. (n.d.). *Electro-hydraulic point machine with variable stroke FieldTrac 6343 L826H* [Brochure]. Retrieved February 20, 2018, from https://myproducts-thales.com/brochures-documents/2-brochure-fieldtrac-6343-l826h/file

[23] Alstom SA. (2015). *P80 point machine* [Brochure]. Paris, France: Author

[24] Alstom SA. (2013). *Hy-drive point machine* [Brochure]. Paris, France: Author

[25] Mission and Objectives of Shift2Rail. Retrieved from https://shift2rail.org/about-shift2rail/mission-and-objectives/

[26] Burt, C., Dr. (2006). *Electric motor efficiency under variable frequencies and loads* (Report No. R 06-004). Retrieved from http://www.itrc.org/reports/pdf/r06004.pdf

[27] Bobak, T.R. (n.d.). *How green is your gearbox?* [Article] Retreived March 03, 2018 from https://eponline.com/~/media/633EB55F69D24B6A913DBA224AE78499.pdf

[28] Xu, H. (2005). Development of a Generalized Mechanical Efficiency Prediction Methodology for Gear Pairs. *The Ohio State University, Columbus, USA.*

[29] Pellegrino, G., Vagati, A., Boazzo, B., Guglielmi, P. (2012). Comparison of induction and PM synchronous motor drives for EV application including design examples. *IEEE Transactions of Industry Applications*, *48(6)*, 2322-2332.

[30] Nanfang, Y., Guangzhao, L., Weiguo, L., Kang, W. (2012). Interior permanent magnet synchronous motor control for electric vehicle using look-up table, IEEE 7th International Power Electronics and Motion Control Conference, Harbin, June 2-5, 2012.

[31] European Committee for Electrotechnical Standardization. (2013). *EN 60529:1992+A2:2013: Degrees of protection provided by enclosures(IP code)*

APPENDICES

A. FUNDAMENTAL RAILWAY TERMS

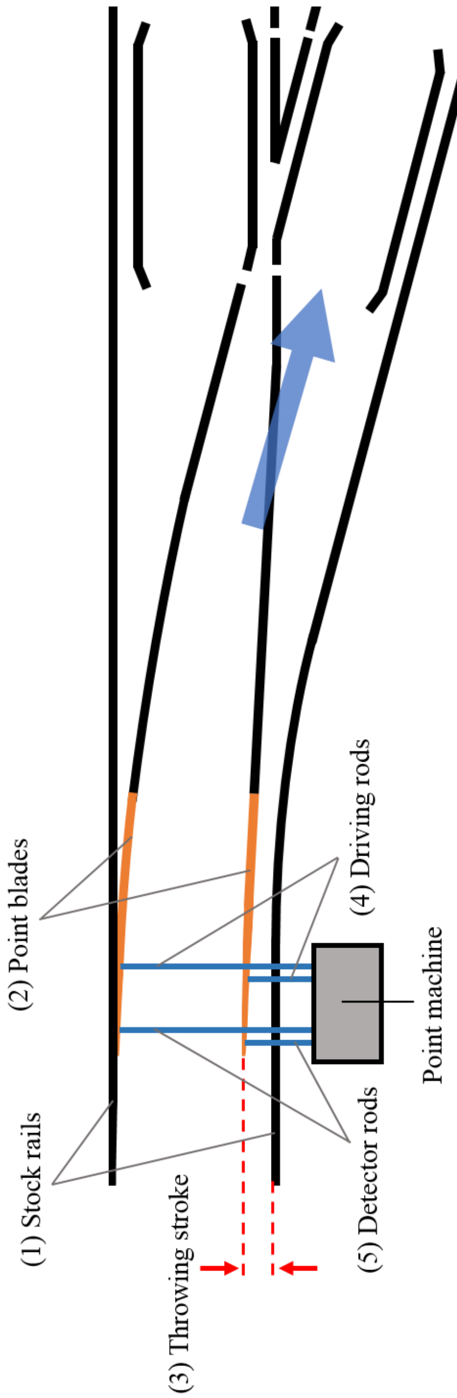


Figure 140 Fundamental parts of a railway point and a point machine

B. LIST OF PATENTS ABOUT THE POINT MACHINES

Table 15 Patent list related with the point machines

	Publication number	Title of the invention	Publication date
1	BR 102016021914-0 A2	Apparatus for operating a switch of a railway track and associated method and switch	04.04.2017
2	DE 4424556 A1	Device for locking tongue rail to cheek rail on railway points	18.01.1996
3	DE 202006013522 U1	Manual locking system for points, including those with movable frogs, comprises clamp which fits over foot of rail and is connected by tie rods to one or two key-operated locks with slides which lock rail in position via tie rods	07.12.2006
4	EP 0156351 A2	Locking device for a switch point	02.10.1985
5	EP 0802102 A1	Switch end lock	22.10.1997
6	EP 0904458 A1	Point operating system	31.03.1999
7	EP 2412603 A1	Railway switch locking device	01.02.2012

8	EP 2620347 A1	Non trailable switch machine for railroad switches or the like	31.07.2013
9	EP 3241718 A1	Trailing module for a switch machine and switch machine	08.11.2017
10	FR 2589495 A1	Device for operating points having point blades, which may be locked and forces open	07.05.1987
11	GB 2540876 A	Railway point crank system	01.02.2017
12	HU E027783 (T2)	Device for controlling a rail switch	28.10.2016
13	KR 100738591 B1	Locking device for turnout	05.07.2007
14	KR 20080015451 A	Device for examining the end position of displaceable parts of a rail switch	19.02.2008
15	KR 20090053329 A	Apparatus for converting railroad	27.05.2009
16	KR 20100026616 A	Lock device of track branching apparatus	10.03.2010
17	KR 20140107844 A	Apparatus for converting rail	05.09.2014
18	US 3691371	Trailable railway switch machine	12.09.1972
19	US 4637579	Railroad switch mechanism	20.01.1987
20	US 4842225	Device for operating a railroad switch	27.06.1989
21	US 4896850	Railroad switch motor system	30.01.1990

22	US 4921189	Universal outer point lock device for railway point	01.05.1990
23	US 5470035	Electrical switch stand	28.11.1995
24	US 5620156	Device operating a switch for rail points	15.04.1997
25	US 5775647	Hydraulic switch stand	07.07.1998
26	US 6270041 B1	Method for locking moveable point sections	07.08.2001
27	US 6454221 B1	Switch box for railway, tramway points, or similar	24.09.2002
28	US 6568641 B2	Electrically operated railroad switch machine	27.05.2003
29	US 7300023 B2	Machine for railway switching	27.11.2007
30	US 7484695 B2	Switch machine for railway and tramway switches or the like	03.02.2009
31	US 7913956 B2	Mechanism for operating switch points	29.03.2011
32	US 2005/0116119 A1	Machine for railway switching	02.06.2005
33	US 2005/0178929 A1	Switch machine with improved switch point connectors	18.08.2005
34	US 2013/0068896 A1	Lock for railway switch actuating devices	21.03.2013
35	US 2014/0252175 A9	Hydraulic switch machine for railroads	11.09.2014
36	WO 2016/193726 A1	Safety lock apparatus for a railway points arrangement	08.12.2016

C. ANALYSIS OF POINT MACHINES

C.1. MATLAB CODE OF POINT MACHINE A

```
clc
clear all
close all
%Constant dimensions on the mechanism:
d1=50; % in [mm]
d2=60; % in [mm]
d3=134; % in [mm]
d4=43; % in [mm]
d5=153; % in [mm]
d6=455; % in [mm]
d7=21; % in [mm]
P=110e+05; % Applied pressure in [Pascal]
N=930; % Motor speed in [rev/min]
U=1.5; % Flow rate of pumped fluid in [cm3/rev]
d_piston=45; % Piston diameter in [mm]
A_p=pi*((d_piston/2)^2); % Area of piston in [mm2]
t=-2.5:0.1:2.5; % time in [s]
s2_ddot=0; % Input acceleration in [mm/s2]
s2_dot=(N*(U*1000)/A_p)/60 % Input velocity in [mm/s]
s2=s2_dot.*t; % Input position in [mm]
theta13=acos(s2/d1); % in [radians]
s1=d1*sin(theta13); % in [mm]
s3=d2*sin(theta13); % in [mm]
s4=d2*cos(theta13); % in [mm]
theta13_dot=-s2_dot./(d1*sin(theta13)); % in [rad/s]
s1_dot=d1*cos(theta13).*theta13_dot; % in [mm/s]
s3_dot=d2*cos(theta13).*theta13_dot; % in [mm/s]
s4_dot=-d2*sin(theta13).*theta13_dot; % in [mm/s]
theta13_ddot=-(d1*cos(theta13).*theta13_dot-
s2_ddot)./(d1.*sin(theta13)); %in [rad/s2]
s1_ddot=d1*cos(theta13).*theta13_ddot-
d1*sin(theta13).*theta13_dot; % in [mm/s2]
s3_ddot=d2*cos(theta13).*theta13_ddot-
d2*sin(theta13).*theta13_dot; % in [mm/s2]
s4_ddot=-d2*cos(theta13).*theta13_dot-
d2*sin(theta13).*theta13_ddot; % in [mm/s2]

%Force Analysis
Fi=P*(A_p/1e+06) % Input force in [N]
F32=Fi; % in [N]
M2=F32*(s1-d4); % in [N.mm]
Fy12=M2/d7; % in [N]
F23=F32; % in [N]
Fy13=0; % in [N]
F43=F23*d1*sin(theta13)/(d2*sin(theta13)); % in [N]
Fx13=F23+F43; % in [N]
F34=F43; % in [N]
Fo=F34 % Output force in [N]
M4=F34*(s3-d5); % in [N.mm]
Fy14=M4/d6; % in [N]
```

```
%Plots
figure
plot(t,s4,'LineWidth',2);
title('Output position over time');
xlabel('time [s]');
ylabel('Output position [mm]');
grid on
hold on
ylim([-150,150]);
figure
plot(t,s4_dot,'LineWidth',2);
title('Output velocity over time');
xlabel('time [s]');
ylabel('Output velocity [mm/s]');
grid on
ylim([0,60]);
figure
plot(t,s1,'LineWidth',2);
title('Position of upper cylinder of link-3 in y-direction over
time');
xlabel('time [s]');
ylabel('Position of upper cylinder of link-3 in y-direction
[mm]');
grid on
ylim([15,55]);
figure
plot(t,s4_ddot,'LineWidth',2);
title('Output acceleration over time');
xlabel('time [s]');
ylabel('Output acceleration [mm/s^2]');
grid on
ylim([-1,1]);
figure
plot(s2,s4,'LineWidth',2);
title('Input position vs Output position');
xlabel('Input position [mm]');
ylabel('Output position [mm]');
grid on
ylim([-150,150]);
hold on
```

C.2. MATLAB CODE OF POINT MACHINE B

```
clc
clear all
close all
% Known and measured (and assumed) parameters
S5=160; % Output stroke in [mm]
t=0:0.05:4; % Switching time in [s]
t1=0.5; % the time that the motor speed stabilizes in [s]
V=110; % Motor operation voltage in [V] (110 V DC)
for k=1:1:81
if t(k)<=t1
    A_eta(k)=2/t1*t(k); % Motor supply current times efficiency
while the motor speed increases in [A]
else
    A_eta(k)=2; % Motor supply current times efficiency after the
stabilization of motor speed in [A]
end
end
Rgb=26/1; % Ratio of gearbox
N2=16; % Number of teeth of gearbox output pinion
N3=85; % Number of teeth of gear (mate of pinion)
Rsg=N3/N2; % Gear ratio between spur gears (pinion and its mating
gear)
e_gb=0.94; % Efficiency of gearbox (assumed)
e_s=0.98; % Efficiency of spur gear mate (assumed)
e_m=0.9; % Efficiency of electric motor (assumed)
e_r=0.98; % Efficiency of rack and pinion gear mate (assumed)
m=8; % Module of driving pinion in [mm]
d=96; % pitch diameter of driving pinion in [mm]
phi=20; % Pressure angle of driving pinion in [degree]
d1=50; % Height of the driving rod in [mm]
d2=10; % Distance of applied load on the driving rod from top
surface in [mm]
d3=215; % Distance of the applied load on the driving rod from
side surface in [mm]
d4=430; % Distance between linear bearings that support driving
rod in [mm]
Ffs=50; % Friction force measured at the linear slides in [N]

% Calculations and Force Analysis
P=V*A_eta; % Electrical power of motor in [W]
for i=1:1:81
if t(i)<=t1
    S5_dot(i)=85.33*t(i); % Velocity of driving rod in [mm/s]
else
    S5_dot(i)=85.33*t1; % Velocity of driving rod in [mm/s]
end
end
% S5_dot=20*(t); % Velocity of driving rod in [mm/s]
w4=60./((d*pi)./S5_dot); % Rotational speed of driving pinion in
[rev/min]
w3=w4; % Rotational speed of gear-3 in [rev/min]
w2=w3*N3/N2; % Rotational speed of gearbox output pinion in
[rev/min]
wm=w2*Rgb; % Rotational speed of motor shaft in [rev/min]
```

```
Tm=((P*e_m)./wm).*60./(2.*pi); % Torque of motor shaft in [N.m]
T2=Tm*Rgb*e_gb; % Torque of gearbox output pinion in [N.m]
T3=T2*Rsg*e_s; % Torque of gear-3 in [N.m]
T4=T3; % Torque of driving pinion in [N.m]
F54_t=T4*e_r/((d/2)*1e-03); % Transmitted load on driving pinion
in [N]
F45_t=F54_t; % Applied load on the driving rod along operation
direction in [N]
F45_r=(F45_t/cos(phi*pi/180))*sin(phi*pi/180); % Applied load on
the driving rod along vertical (radial) direction in [N]
Fo=F45_t-Ffs; % Operation force by the driving rod in [N]
Fy15c=(F45_r*d3-F45_t*(d1/2-d2))/d4; % Vertical reaction force on
linear bearing c in [N]
Fy15b=F45_r-Fy15c; % Vertical reaction force on linear bearing b
in [N]

%Plots
figure
plot(wm,P,'LineWidth',2)
title('Power vs Rotational speed of the motor');
xlabel('Rotational speed [rpm]');
ylabel('Power [W]');
ylim([0,300]);
xlim([0,1400]);
grid on
hold on
figure
plot(t,wm,'LineWidth',2)
title('Rotational speed of the motor vs time');
xlabel('time [s]');
ylabel('Rotational speed [rpm]');
ylim([0,1500]);
xlim([0,5]);
grid on
hold on
figure
plot(t,Tm,'LineWidth',2)
title('Motor torque vs time');
xlabel('time [s]');
ylabel('Torque [N.m]');
ylim([0,3]);
xlim([0,5]);
grid on
hold on
figure
plot(t,Fo,'LineWidth',2)
title('Net force applied on the point blades');
xlabel('time [s]');
ylabel('Force [N]');
ylim([3500,4500]);
xlim([0,5]);
grid on
xlim([0,5]);
hold on
figure
plot(t,P,'LineWidth',2)
title('Power of the motor vs time');
xlabel('time [s]');
ylabel('Power [W]');
```

```
ylim([0,300]);
xlim([0,5]);
grid on
hold on
figure
plot(t,S5_dot,'LineWidth',2)
title('Velocity profile of the driving bar');
xlabel('time [s]');
ylabel('Velocity [mm/s]');
ylim([0,50]);
xlim([0,5]);
grid on
hold on
```

C.3. MATLAB CODE OF POINT MACHINE C

```
clc
clear all
close all
%Constant parameters on the mechanism:
P=110e+05; % Maximum pressure generated by the pump in [P]
N=890; % Motor speed in [rev/min]
U=1.7; % Flow rate of pumped fluid in [cm3/rev]
d_piston=28; % Piston diameter in [mm]
A_p=pi*((d_piston/2)^2); % Area of piston in [mm2]
s=0:1:163; % stroke in [mm]
s_ddot=0; % Input acceleration in [mm/s2]
s_dot=(N*(U*1000)/A_p)/60; % Input velocity in [mm/s]
t=s/s_dot; % Throwing time in [s]
r=35/2; % Radius of trailing cylinder in [mm]
k=420; % Spring constant [N/mm]
x=13:0.1:17.2; % Adjustable contraction distance of the spring in
[mm]
alpha=acos(12/r); % Angle of reaction force of shutter plate with
the vertical at the beginning of trailing in [radians]

%Force Analysis
Fi=P*(A_p/1e+06); % Input force in [N]
Fx36=Fi; % in [N]
Fx63=Fx36; % in [N]
% At the beginning of the motion, one driving rod is pushed first.
Fx43=Fx63; % in [N]
Fx34=Fx43; % in [N]
Fx24=Fx34; % in [N]
Fx42=Fx24; % in [N]
F02=Fx42; % in [N]

%After the backlash is disappeared both driving rods are pushed.
Fx36=Fi; % in [N]
Fy36=500; % in [N]
alpha=atan2(Fx36,Fy36);
d1=(170/2)-(r*sin(alpha)); % in [mm]
d2=170-d1; % in [mm]
d3=90; % in [mm]
d4=20; % in [mm]
d5=24; % in [mm]
Fy36r=(Fy36-(Fi*(d3/d1)))/(1+(d2/d1)); % in [N]
Fy36p=Fy36-Fy36r; % in [N]
Fy63=Fy36; % in [N]
Fx63=Fx36; % in [N]
Fy63p=Fy36p; % in [N]
Fy63r=Fy36r; % in [N]
Fx53=((Fy63p*d1)-(Fy63r*d2)-(Fx63*d4))/(d5-d4); % in [N]
Fx43=Fx63-Fx53; % in [N]

% Trailing force calculations
Fs=k*x; % Spring forces at the normal operations in Newtons
Fsp_v=k*(x+5.5); %
Fsp=Fsp_v/cos(alpha); %
Fsp_h=Fsp*sin(alpha); %
```

```
% Plots
figure
plot(t,s,'LineWidth',2);
title('Throwing distance over time');
xlabel('time [s]');
ylabel('Throwing distance [mm]');
grid on
```

C.4. MATLAB CODE OF POINT MACHINE D

```
clc
clear all
close all
% Known, measured and assumed parameters
S10=170; % Output stroke in [mm]
t=0:0.05:8; % Switching time in [s]
t1=0.5; % the time that the motor speed stabilizes in [s]
V=24; % Motor operation voltage in [V] (24 V DC)
for k=1:1:161
if t(k)<=t1
    A_eta(k)=4/t1*t(k); % Motor supply current times efficiency
while the motor speed increases in [A]
else
    A_eta(k)=4; % Motor supply current times efficiency after the
stabilization of motor speed in [A]
end
end
N2=20; % Number of teeth of gear 2
N3=61; % Number of teeth of gear 3
N4=14; % Number of teeth of gear 4
N5=58; % Number of teeth of gear 5
N6=15; % Number of teeth of gear 6
N7=40; % Number of teeth of gear 7
N8=16; % Number of teeth of gear 8 (driving pinion)
N9=N8; % Number of teeth of gear 9 (driving pinion)
R76=N7/N6; % Gear ratio between spur gear pair (7 and 6)
R54=N5/N4; % Gear ratio between spur gear pair (5 and 4)
R32=N3/N2; % Gear ratio between spur gear pair (3 and 2)
e_s=0.98; % Efficiency of spur gear mates (assumed)
e_m=0.90; % Efficiency of electric motor (assumed)
e_r=0.98; % Efficiency of rack and pinion gear mates (assumed)
m=5.5; % Module of driving pinions in [mm]
d=88; % pitch diameter of driving pinions in [mm]
phi=20; % Pressure angle of driving pinions in [degree]
d1=40; % Height of the driving rod in [mm]
d2=6; % Distance of applied load on the driving rod from top
surface in [mm]
d3=100; % Distance of the applied load on the driving rod from
side surface in [mm]
d4=200; % Distance between linear bearings that support driving
rod in [mm]
Ffs=80; % Frictional force measured at the linear slides in [N]
Fo=200*9,81;

% Calculations and Force Analysis
P=V.*A_eta; % Electrical power of motor in [W]
for i=1:1:161
if t(i)<=t1
    S5_dot(i)=43.87*t(i); % Velocity of driving rod in [mm/s]
else
    S5_dot(i)=43.87*t1; % Velocity of driving rod in [mm/s]
end
end
```

```
w8=60./((d*pi)./S5_dot); % Rotational speed of driving pinion in
[rev/min]
w7=w8; % Rotational speed of gear-7 in [rev/min]
w6=w7*R76; % Rotational speed of gear-6 in [rev/min]
w5=w6; % Rotational speed of gear-5 in [rev/min]
w4=w5*R54; % Rotational speed of gear-4 in [rev/min]
w3=w4; % Rotational speed of gear-3 in [rev/min]
w2=w3*R32; % Rotational speed of motor shaft in [rev/min]
T2=((P*e_m)./w2).*60./(2.*pi); % Torque of motor shaft in [N.m]
T3=T2.*e_s.*R32; % Torque of gear-3 in [N.m]
T4=T3; % Torque of gear-4 in [N.m]
T5=T4.*e_s.*R54; % Torque of gear-5 in [N.m]
T6=T5; % Torque of gear-6 in [N.m]
T7=T6.*e_s.*R76; % Torque of gear-7 in [N.m]
F810_t=Fo+Ffs; % Tangential force applied by the driving pinion in
[N]
T8=F810_t*((d/2)*1e-03)/e_r; % Torque of gear-8 in [N.m]

%Plots
figure
plot(w2,P,'LineWidth',2)
title('Power vs Rotational speed of the motor');
xlabel('Rotational speed [rpm]');
ylabel('Power [W]');
grid on
hold on
figure
plot(t,w2,'LineWidth',2)
title('Rotational speed of the motor vs time');
xlabel('time [s]');
ylabel('Rotational speed [rpm]');
xlim([0,10]);
ylim([0,200]);
grid on
hold on
figure
plot(t,T2,'LineWidth',2)
title('Motor torque vs time');
xlabel('time [s]');
ylabel('Torque [N.m]');
xlim([0,10]);
ylim([0,7]);
grid on
hold on
figure
plot(t,S5_dot,'LineWidth',2)
title('Velocity profile of the driving bar');
xlabel('time [s]');
ylabel('Velocity [mm/s]');
xlim([0,10]);
ylim([0,35]);
grid on
figure
plot(t,P,'LineWidth',2)
title('Power of the motor vs time');
xlabel('Time [s]');
ylabel('Power [W]');
xlim([0,10]);
ylim([0,150]);
```

```
grid on
hold on
figure
plot(t,S5_dot,'LineWidth',2)
title('Velocity profile of the driving bar');
xlabel('time [s]');
ylabel('Velocity [mm/s]');
ylim([0,30]);
xlim([0,10]);
grid on
hold on
```

D. DEGREES OF PROTECTION PROVIDED BY ENCLOSURES

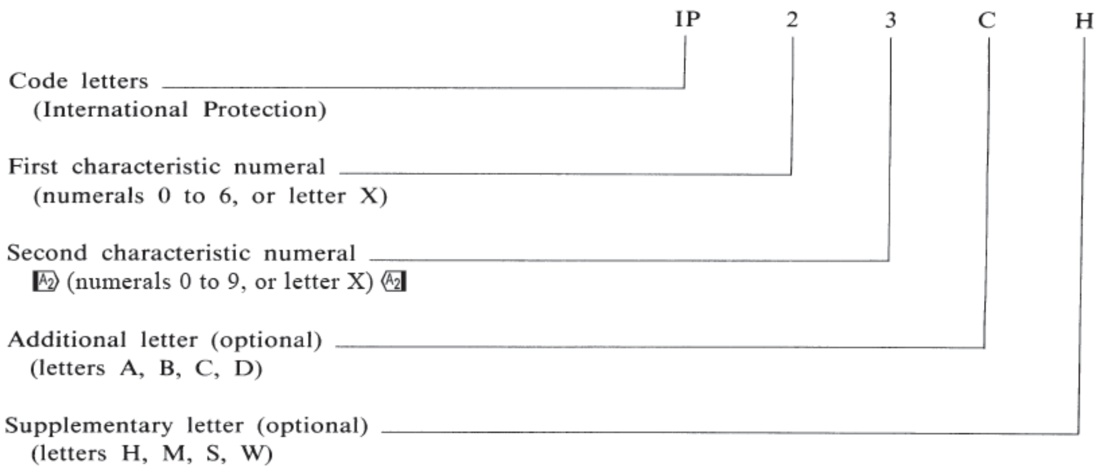


Figure 141 Arrangement of the IP Code (Section 4.1 in [31])

Element	Numerals or letters	Meaning for the protection of *equipment*	Meaning for the protection of *persons*
Code letters	IP	—	—
First characteristic Numeral		Against ingress of solid foreign objects	Against access to hazardous parts with
	0	(non-protected)	(non-protected)
	1	≥50 mm diameter	back of hand
	2	≥12,5 mm diameter	finger
	3	≥2,5 mm diameter	tool
	4	≥1,0 mm diameter	wire
	5	dust-protected	wire
	6	dust-tight	wire
Second characteristic numeral		Against ingress of water with harmful effects	—
	0	(non-protected)	
	1	vertically dripping	
	2	dripping (15° tilted)	
	3	spraying	
	4	splashing	
	5	jetting	
	6	powerful jetting	
	7	temporary immersion	
	8	continuous immersion	
	A2 9 A2	A2 high pressure and temperature water jet A2	
Additional letter (optional)		—	Against access to hazardous parts with:
	A		back of hand
	B		finger
	C		tool
	D		wire
Supplementary letter (optional)		Supplementary information specific to:	—
	H	High-voltage apparatus	
	M	Motion during water test	
	S	Stationary during water test	
	W	Weather conditions	

Figure 142 Brief description of IP designation (Section 5.1 in [31])