Institut für Textiltechnik und Lehrstuhl für Textilmaschinenbau

RWTH AACHEN UNIVERSITY

The work was submitted to the

Institut für Textiltechnik der RWTH Aachen University

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Development of a device for the positioning of a projectile in high speed magnetic weft insertion for weaving machines

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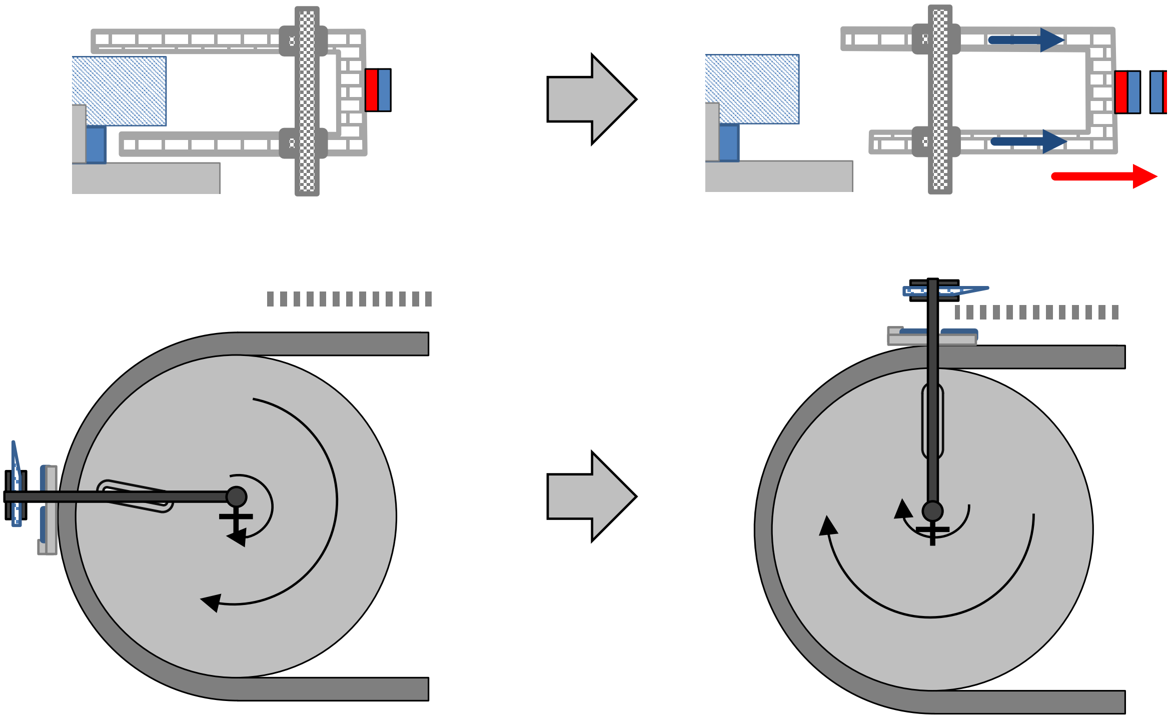
Aachen, August 2017



2017
Bachelor thesis

Development of a device for the positioning of a projectile in high speed magnetic weft insertion for weaving machines

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Short version:

The magnetic weft insertion for weaving machines is being developed to combine the advantages of common methods of weft insertions such as rapier, projectile and air-jet weaving. The novel method of weft insertion is currently being tested by the use of a demonstrator at ITA. To fulfil a yarn transport at target insertion speeds of up to 1000 insertions per minute central challenges have to be overcome. The safe positioning of the magnetic projectile for preparation of the weft insertion is one central challenge.

Objective of this thesis:

In present work a device for the safe positioning of the magnetic projectile is being developed. This device shall be able to avoid a loss of the magnetic projectile due to centrifugal forces in rotational areas of the moving path. Additionally the device shall be able to position the projectile correctly and smoothly for the initiation of next weft insertion at the target insertion speeds.

Solution process:

According to VDI 2221 a mechanical design process is being carried out. After a clarification of the task, requirements are identified. The investigation of the current set-up of the demonstrator is used to support the definition of requirements. Subsequently the investigation of necessary functions and their structure follows. This functional structure is then used to develop principle solutions and basic concepts to fulfil respective sub-functions. By evaluating the fulfilment of requirements of the developed concepts a selection of a combination of principal concepts is carried out. Thus a general concept is being described in preliminary layouts.

Key results:

Key results are a list of requirements for the developed device and a description of the respective functional structure. Additionally basic concepts are developed for the fulfilment of these functions. With regard to the fulfilment of requirements a combination of principal concepts is selected for the creation of preliminary layouts. These preliminary layouts are a basis for further creation of definitive layouts and the manufacturing of functional models.

Key word: Magnetic weft insertion, preparation of weft insertion, centrifugal force, positioning device, VDI 2221.

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1 Introduction and Objectives

Weaving is one of the oldest processes for the production of textile fabrics. Over time, various weaving techniques were developed with different characteristics. The different characteristics between weaving techniques are found mainly in the type of yarn insertion and in the shedding. The focus of the research and development of new technologies is to increase productivity and at the same time to increase energy efficiency. Furthermore, it is aimed at the production of high quality fabrics with a flexibility in the processing of different yarn materials.

Until now, a fabric was created by crossing warp and weft threads at a right angle, although the insertion method made a large leap during the last two centuries. Nowadays, the most common weft insertion methods are weft insertion by compressed air or water, by rapier or projectile or by shuttle. An overview of weft insertion methods and their characteristics is shown in Tab. 1.1.

Tab. 1.1: Overview of weft insertion methods and their characteristics [JKR17]

Weft insertion characteristic	Rapier	Projectile	Air-jet
Weft insertion rate [m/min]	1200	1550	2000
Processability of yarn material	Any yarn	No sensitive yarns	No heavy or flat yarns
Energy consumption [kWh]	6	4	12

Air jet weaving grants the highest productivity at a maximum weft insertion rate of up to nearly 4000 m/min (Tsudakoma WLT at ITMA 2015). The high productivity goes along with high energy consumption due to processing of compressed air (12kWh for a single air jet weaving machine). In addition, air jet weaving is limited in its ability to process different yarn materials.

Rapier weaving is the most flexible weft insertion method, granting a gentle transport of any yarn material. Due to the high mass of the moving parts and the acceleration and deceleration of the alternating movement of the rapiers, the productivity is limited.

The weft insertion granting the lowest energy consumption is projectile weaving with about 4 kWh. Due to the high acceleration at initiation of movement, an impact load is applied to the yarn. Only yarns with sufficient tensile strength can be transported by projectile weaving.

At the Institute for Institut für Textiltechnik (ITA) der RWTH Aachen University, a magnetic weft insertion method has been developed, that has the potential to combine all the positive properties of conventional weaving [JKR17].

A demonstrator of the magnetic weft insertion process has been developed and built. With this, the basic function of the new weaving process has been demonstrated [JKR17]. The schematic structure of the developed prototype is shown in Fig. 1.1.

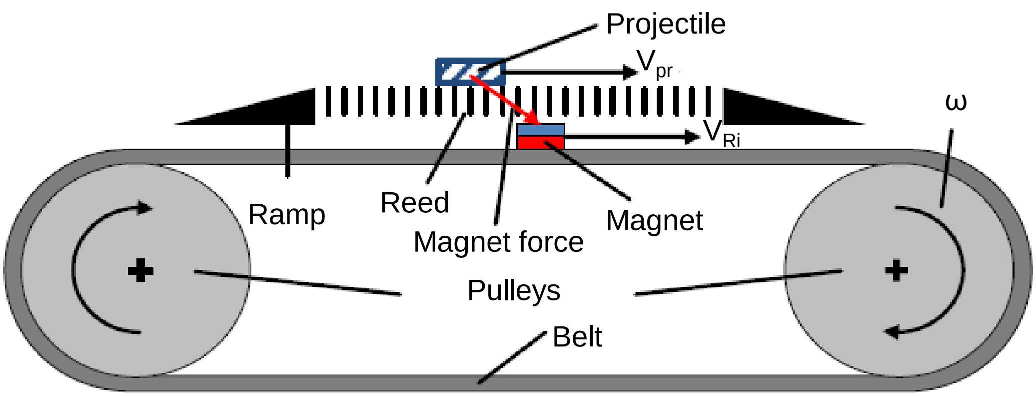


Fig. 1.1: Schematic design of the prototype [Str14]

In the functional testing of the demonstrator, certain problems were identified. A significant challenge is the centrifugal in rotational areas of passing projectile as well as the correct alignment of the projectyle at the entrance of the reed. Since the projectile rotates at high speed, the magnetic force cannot keep the projectile in the right trajectory. In the current design of the demonstrator, a simple ramp is used to lift the projectile to the reed. The aim of this work is to develop a device to contrarrest the centrifugal force in rotational areas of passing projectile as well as replace the actual ramp.

After the introduction into the weaving technique, the method of design is presented. At the beginning of this work the main problems are realised, the important components of the machine are recognized and the critical parts which must be respected without modifications are identified.

In the first step of the development process, the method of designing is described. After, the device is characterized. Finally, an overall solution is suggested for realization.

2 State of the art

At the beginning of this chapter, an introduction to weaving is presented. An introduction to methods of weft insertion follows. The magnetic weft insertion is exposed in more detail with a discussion on the current state of validation on test-benches and an outlook of the development.

2.1 Introduction the weaving technique

Weaving is defined as the interlacement of two thread systems that are arranged perpendicularly, warp and weft yarn. The yarn system running in production direction is called warp yarns. In Fig. 2.1, the basic structure of a loom or weaving machine is illustrated. The warp yarns are assembled in desired number and yarn density on the warp beam. The let-off mechanism releases the warp yarn from the warp beam as the wrap yarn is woven into the fabric. The let-off mechanism applies tension to the warp yarns by controlling the rate of flow of warp yarns [Ada01].

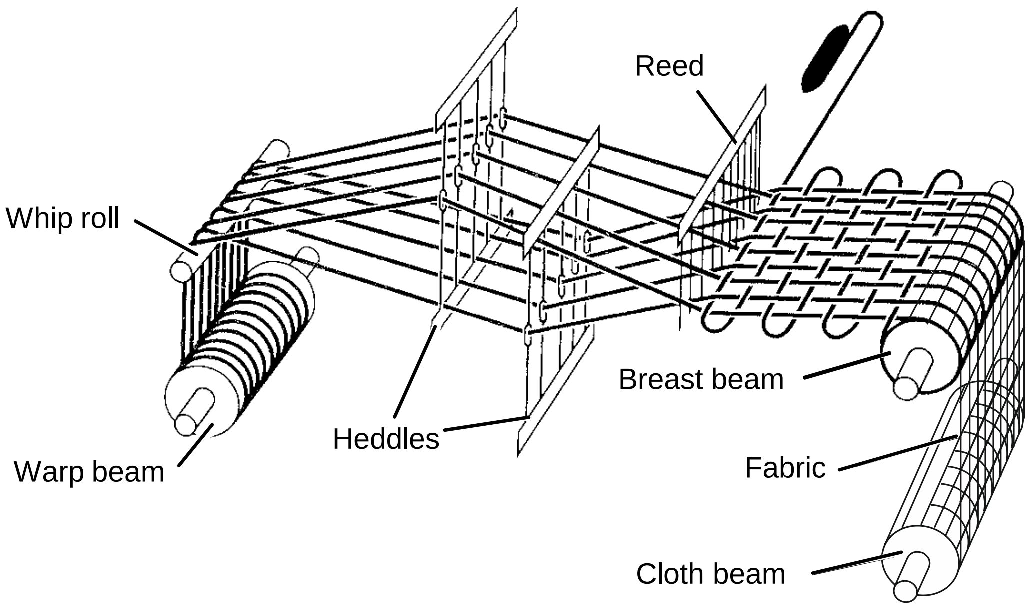


Fig. 2.1: Dobby loom basic structure [WGV06]

Warp threads are guided over the whip roll and then through the heddles from the warp beam. On heddles, warp yarns corresponding to required number of threads are disposed alternatively. For shedding at least two heddles must be present. Shed is formed by an opposing upward and downward movement of heddles.

Through the opened shed, the weft yarn is inserted perpendicular to production direction. This process is called weft insertion. To input the weft yarn, there are several possibilities. The different possibilities of weft insertion are exposed at the following subchapters. Before shedding, filling yarn is beaten up by reed and fixed into the fabric. Finally the fabric is transported in vertical direction by breast beam to be stored into the cloth beam [Ada01].

2.2 Methods of weft insertion

In this chapter, different types of weft insertion are described. Main differences between these types of weft insertion are discussed

2.2.1 Shuttle weaving

Weft insertion with shuttle as shown in Fig. 2.2, is the oldest weft insertion system. Nowadays, shuttle weaving has become a high-tech manufacturing method.

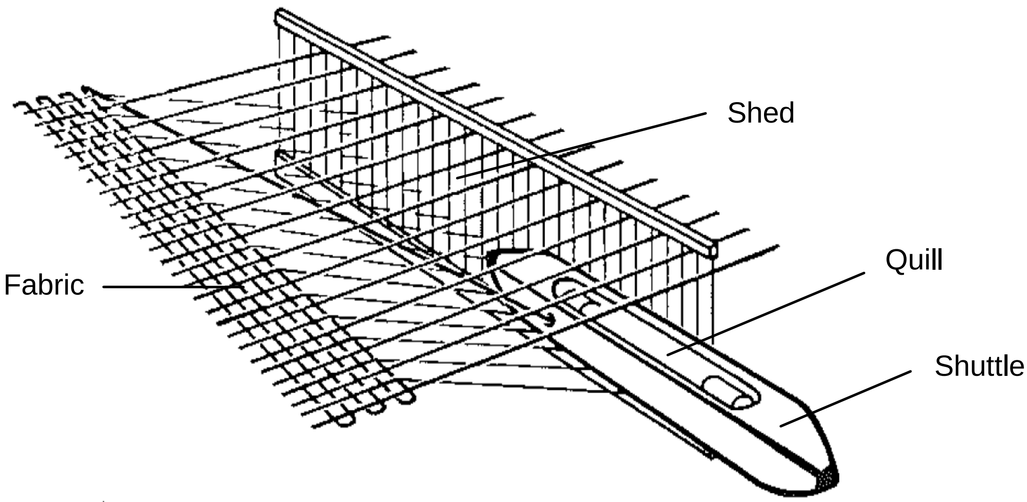


Fig. 2.2: Shuttle weft insertion [WGV06]

During the shuttle trajectory into the shed, the weft yarn is unwound from the quill and laid into the shed perpendicularly to the fabric direction. After the shuttle has completely crossed, the weft thread is beaten up by the reed. Then, after shedding, the same process is repeated by inserting the weft yarn in the opposite direction of the previous insertion. As the weft yarn is not out, a true selvedge is formed. This type of selvedge grants a high quality and stability in the zones of the fabric edges.

Standard shuttle insertion is an inefficient process in the sense that the shuttle weighs around 0.5 kg while the weight of the inserted yarn at one pick is less than 1/1000 of the shuttle weight. As a result, other forms of filling insertion without a shuttle have been developed which replaced shuttle weaving [Ada01].

For highest requirements, shuttle weaving is very valuable process as it allows manufacturing of unique technical fabric constructions e.g. medical and aerospace applications.

2.2.2 Projectile weaving

During the weaving process with projectile, the weft yarn is held in a projectile and then transported through shed. After the weft insertion, beat-up movement takes place and projectile returns to the initial position. Compared to shuttle weaving, the weft yarn bobbin is separated of the projectile entailing a great reduction of weight in motion. The projectile return takes place outside the compartment. Therefore, different projectiles are needed [Ada01]. In Fig. 2.3, the projectile weft insertion is shown. Weft yarn is engaged to the guided projectile to cross the shed.

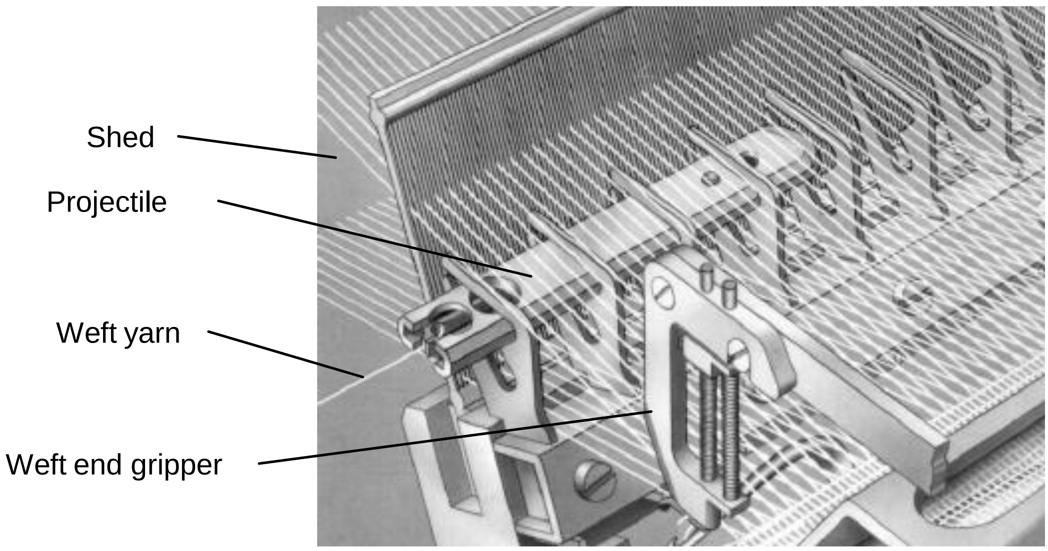


Fig. 2.3: Projectile weft insertion [www12a]

2.2.3 Rapier weaving

Rapier weaving machines are known for their reliability, performance and yarn material versatility, i.e. ability to weave a wide range of fabrics. During the weaving process, the weft yarn is attached to a gripper and is carried into the open shed. Weft yarn is then unwound from a supply reel. When the first gripper has reached the middle part of the fabric, the yarn is passed to a second gripper, which is introduced from the opposite side in the shed as shown in Fig. 2.4.

Possible disadvantages of rapier weaving include the following:

- Warp threads can be damaged by the ribbed guides.
- Guiding system may lead to warp end breakages due knot failures.
- Using fancy yarns in warp direction is almost impossible.
- Max productivity of weft insertion around 1200 m/min [Eme06].

Basic gripper motion described before is composed of the following steps:

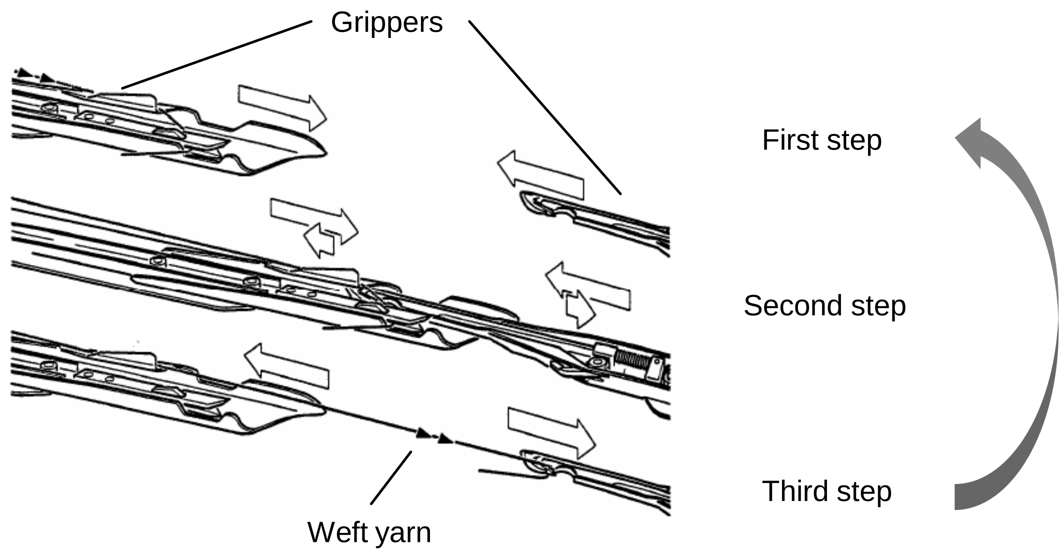


Fig. 2.4: Gripper motion [Eme06]

2.2.4 Jet weaving

A distinction is made between air-jet weaving and water jet weaving. Both methods differ in terms of the transport medium for transporting the weft thread. In the following, the operating principle of the air-jet weaving will be explained.

Air-jet weaving is a type of weaving in which the weft yarn is inserted into the warp shed with compressed air. Yarn is drawn from a filling support package by the filling feeder and each pick is measured for the filling insertion by means of a stopper. Upon release of the filling yarn by the stopper, the filling is fed into the tunnel via tandem and main nozzles. The tandem and the main nozzle combination provides the initial acceleration, whereas the relay nozzles provide the high air velocity across the shed. Profiled reed provides guidance for the air and separates the filling yarn from the warp. A cutter is used to cut the yarn when the insertion is completed. Fig. 2.5 shows an air-jet weaving machine [Ada01].

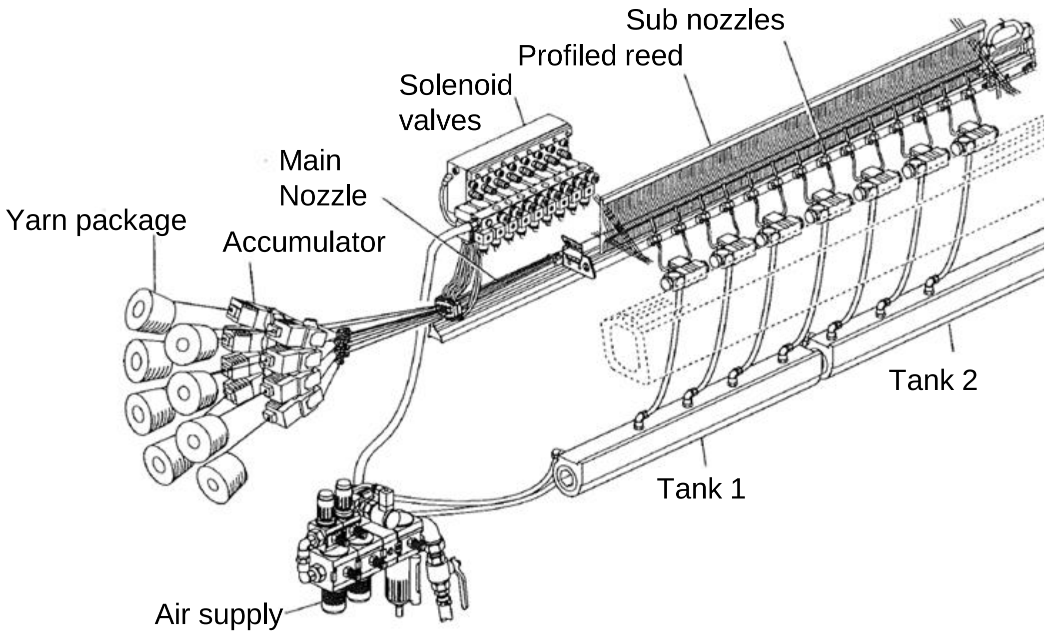


Fig. 2.5: Components for the weft insertion with air nozzles [NN97]

The air-jet weaving machine combines high performance with low manufacturing requirements. It has an extremely high insertion rate. Due to its exceptional performance, the air-jet weaving machines are used primarily for the economical production of standard fabrics, covering a wide range of styles. Meanwhile, niches and special fabric segments are covered by this type of weaving technique.

The insertion medium mass to be accelerated is very small, relative to the shuttle, rapier or projectile machines, which allows a high running speeds. The advantages of air-jet weaving machines are [Ada01]:

- high filling insertion rates
- simple operation and reduced hazard
- reduced space requirements
- low spare parts requirement
- reliability and minimum maintenance

2.2.5 Multiphase weaving

Multiphase weaving is a special process. The basic structure is as shown in Fig. 2.6. It has a filling insertion rate of over 5000 m/min being the most productive process on the market [Ada01].

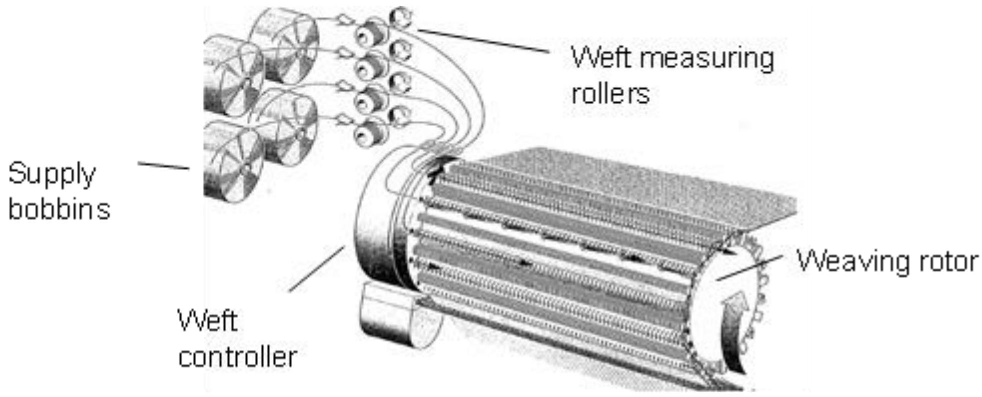


Fig. 2.6: Multiphase weaving machine [Ada01]

This concept is drastically different than single phase machines. The weaving rotor structure is as shown in Fig. 2.7. In the filling direction shed wave principle, a number of sheds in weft direction are opened subsequently for the insertion of the weft. Shed are arranged wave-like from one side to another so that weft carrier slides into each shed. As the weft carrier enters one portion of the warp, the shed is formed; as the carrier leaves that area, the shed changes. The action may occur simultaneously across the width of the warp continually. As a result, at any moment, there are several shuttles in the shed, each carrying a different yarn [Ond09].

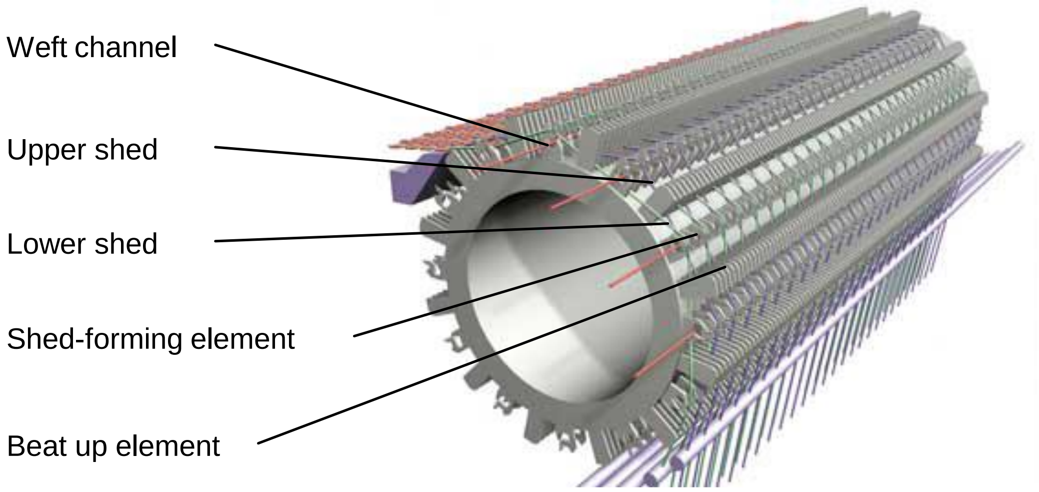


Fig. 2.7: Weaving rotor structure [Str14].

Therefore, is it appropriate to consider the multiphase weaving machines as the third generation of weaving machines [Ada01].

2.3 Magnetic weft insertion

Nowadays, magnetic weft insertion process which uses a magnetic projectile in combination with a circulating belt, is still under research and development. The weft yarn is clamped in a permanent magnetic projectile. Permanent magnets are attached to the belt, which is aligned beneath the shed. If the magnets move under the shed, their magnetic field interacts with the projectile magnetic field and drives the projectile through the shed.

The striking advantage of weft insertion via the magnetic timing belt is the use of continuous movement for the yarn transport while avoiding the necessity of a complex and high dynamic control of electromagnetic fields, as imperative in maglev-weaving. Due to the principle of using a continuous movement, which only has to be accelerated at initiation of the fabric production process, a massive potential of energy saving can be achieved. To investigate and overcome the challenges of weft insertion via the magnetic timing belt, a prototype as shown in Fig. 2.8 was designed and assembled with which functional tests were carried out [JKR17].

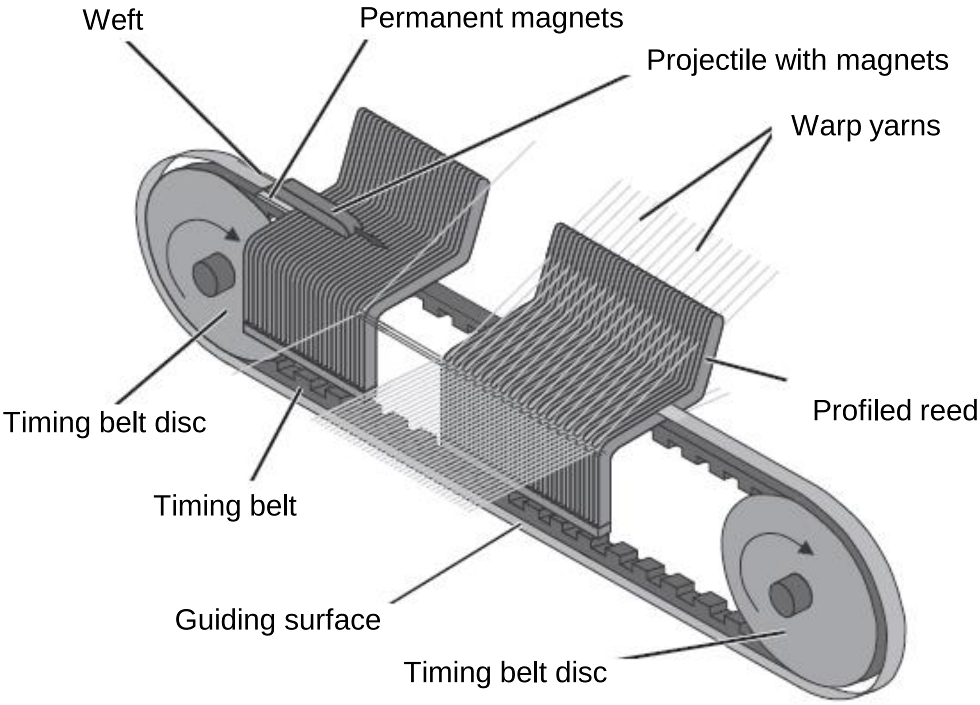


Fig. 2.8: Magnetic weft insertion with a circulating timing belt [JKR17]

The projectile used as shown in Fig. 2.9, consists of a body which is mounted on a magnet and a clamping piece to clamp the weft yarn. The shell is made of fiberglass reinforced plastic (FRP). For better sliding properties a tape of poly-tetrafluoroethylene

(PTFE) is mounted at the bottom. A neodymium magnet is used for the realization of the magnetic coupling between the belt and the projectile [Str14].

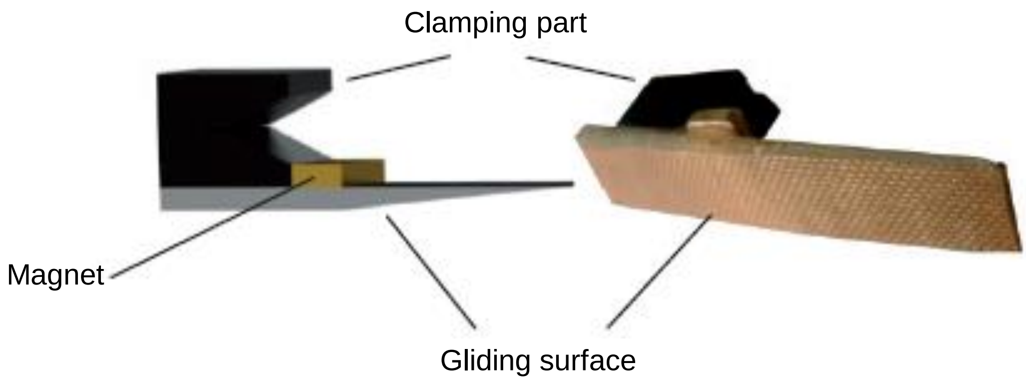


Fig. 2.9: Magnetic projectile [JKR17]

On account of high friction that occurs between the magnetic projectile and the ferro-magnetic reed, a new flying projectile is in research.

Due to the high centrifugal force during rotation at target speeds (e.g. 500N at 1200 weft insertions per min) and the actual ramp to release the projectile from the belt and position at the edge of the reed, the complete process cannot be performed at target speeds [JKR17].

To avoid these problems, a new device will be developed in the present work to secure the projectile to escape the desired trajectory and replace the actual ramp to position the projectile at the reed entrance.

3 Description of challenges identified in current set-up of demonstrator

During this chapter, the challenges identified in current set-up of demonstrator which shall be solved are presented. The first challenge is to avoid a less of the projectile due to the high centrifugal forces in the rotating areas of the passage. The second challenge is the correct positioning of the projectile for the initiation of next weft insertion.

3.1 Centrifugal force

With the prototype characteristics mentioned before where the magnetic weft insertion take place, there are two critical parts of the projectile trajectories where the centrifugal force appears, the two belt pulleys. In Fig. 3.1, the return of the projectile is considered. The balance of forces around the projectile, deflect the projectile by the pulley. To measure this balance of forces, the centrifugal force is named as F_z, the projectile speed is named as v_{pr} and the magnet force is named as F_M. The relevant parameters to be considered are the magnetic force, height, length, width, weight, and shape of the magnet and projectile, the angular velocity and the distance to the projectile mass centre.

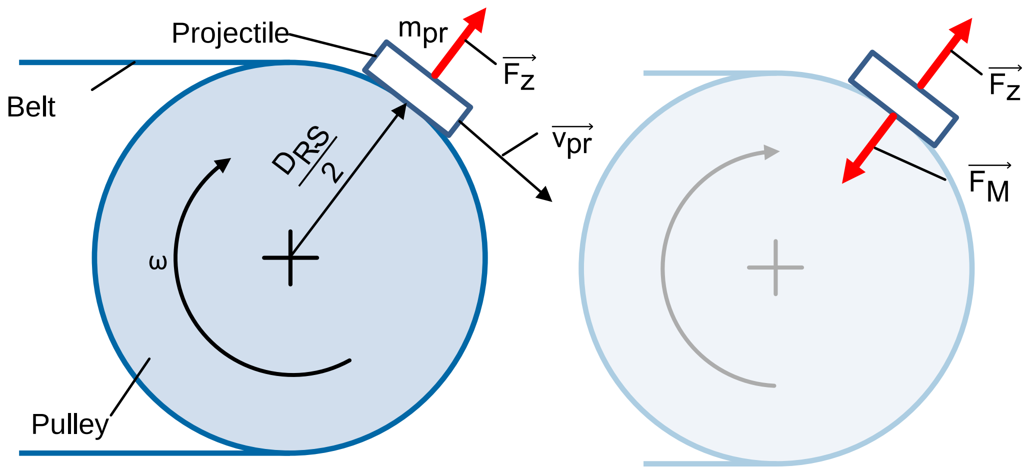


Fig. 3.1: Balance of forces around the projectile passing a pulley [Str14]

Several tests have been made with the actual prototype to check, improve and evaluate all the functions with the respective mechanical and electronical parts. Those functions take place simultaneously during the weft insertion.

In terms of centrifugal force, there are possible failure modes during the rotation of the projectile on the wheels as shown in Fig. 3.2.

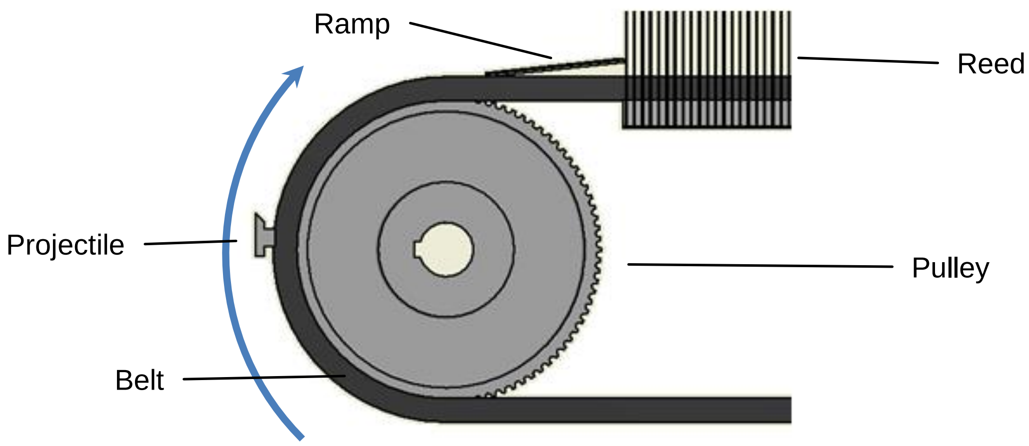


Fig. 3.2: Projectile rotation on wheel [Jor16]

Possible failure modes are: The projectile flies off the magnet, the magnetic force is less than centrifugal force or there is a lag in the projectile position and the magnet. For those failures, possible origins are:

- Magnets are not strong enough
- Weight of projectile is too high
- Rotations per minute are too high
- Magnetic force is less than centrifugal force

The most important effects due to the previous failure models there are:

- The complete system fails
- Failure to pick up yarn in next step
- Damage of other parts of the machine

The failure modes effects are unacceptable to the correct operation of the demonstrator. Therefore, the origins not only need to be studied in a conceptual way but calculations of parameters such as the centrifugal force are also needed. In the following chapters the centrifugal force will be studied in detail.

3.2 Projectile positioning for the next weft insertion

The projectile is transported from the bottom to the top part of the pulley on the surface of the toothed belt for the next weft insertion. This is based on a projectile velocity that is constant equal to the belt speed. As it's shown in Fig. 3.3, for a new weft insertion the projectile has to go up the distance h_{rr} and travel the distance l_{rr} to the guide surface on the reed. This path corresponds to the distance in both axis between the pulley top surface and the left edge of the reed. At the pulley top surface, the toothed belt moves in a horizontal position. To transfer the projectile to the level of the reed releasing it from the belt surface, a properly trajectorie needs to be defined.

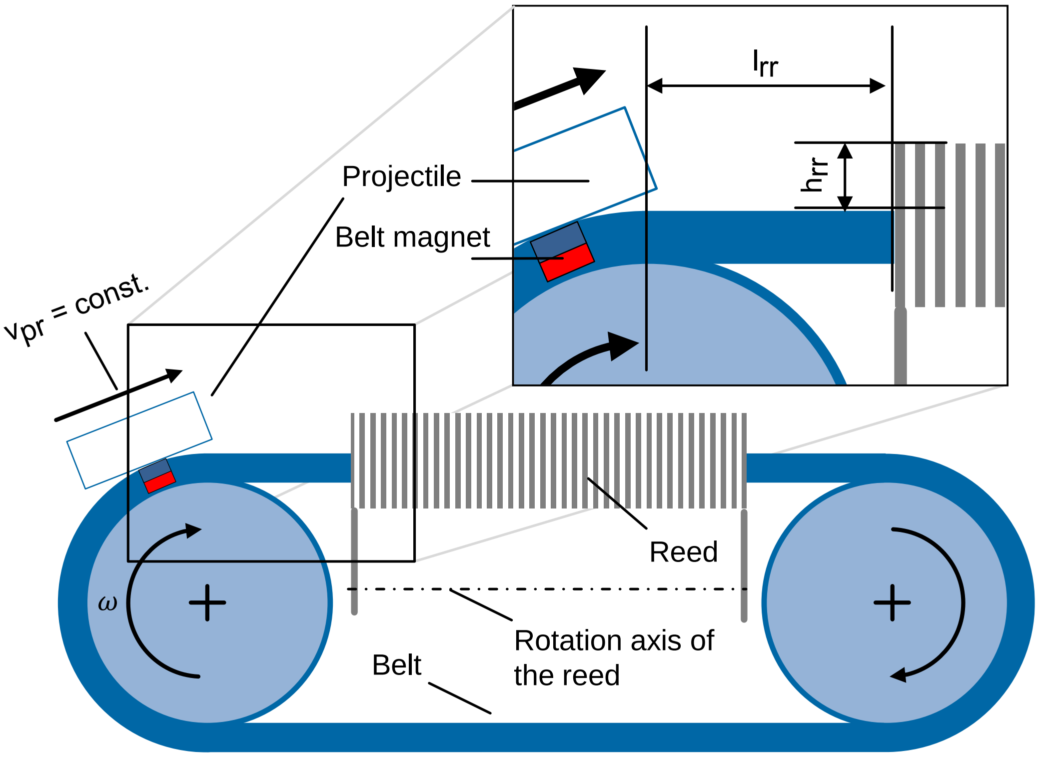


Fig. 3.3: Transfer of the projectile from belt surface to reed [Str14]

The current solution for this assignment is achieved with a stainless steel sheet ramp in both sides of the reed. However, due to the aggressive entrance at the ramp and the friction during the pass of the projectile, this ramp should be removed and replaced for another device to achieve the same purpose but without the deficits of the ramp.

3.2.1 Failure modes during the projectile transfer from belt to reed

In terms of the projectile transfer from belt to reed, there are possible following failure modes during the ascension of the projectile on the ramp as shown in Fig. 3.4.

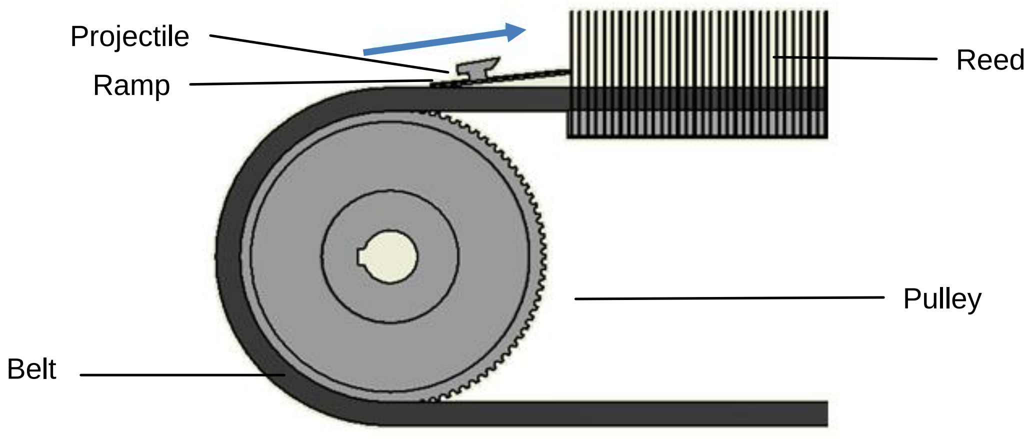


Fig. 3.4: Ascend of Projectile on ramp [Jor16]

Possible failure modes are: Projectile does not climb up the ramp, the projectile path is blocked or the projectile rotates and loses correct alignment there are possible failure models. For those failures, possible origins are:

- Belt vibrations have changed the projectile position
- Not enough revolutions per minute
- Transfer takes place after the top surface of the wheel
- The opposing forces are very large

The most important effects due to the previous failure models are:

- Yarn pickup does not occur
- Probable damage to ramp and magnets
- Contact loss between magnet and projectile

3.2.2 Failure modes during the projectile transfer from reed to belt

In terms of the projectile transfer from reed to belt during the projectile descent on the ramp, there are possible failure modes: Projectile does not climb down the ramp, path of the projectile is blocked and projectile rotates and loses correct alignment.

The most important effects due to the previous failure models there are:

- Yarn release does not occur
- Probable damage to ramp and magnets
- The projectile does not continue along with the magnet

As previously shown, the failure modes effects are unacceptable. In the next chapters, solutions to ensure the correct working performance will be studied.

4 Methodology for development and design of a device

In the following chapter, the development of a device to solve the previous explained problems will be described. The applied design process is based on the insights defined at VDI 2221.

The methodical engineering process according to VDI 2221 is structured into seven work steps as shown in Figure 4.1. The results of each work step represent the necessary input information for the following work step. Depending on the task the different work steps have to be fulfilled completely, partly or iteratively. These work steps can be summarised in groups to development and engineering phases, which represent a basis for the coordination of milestones and corresponding processes [Sch17].

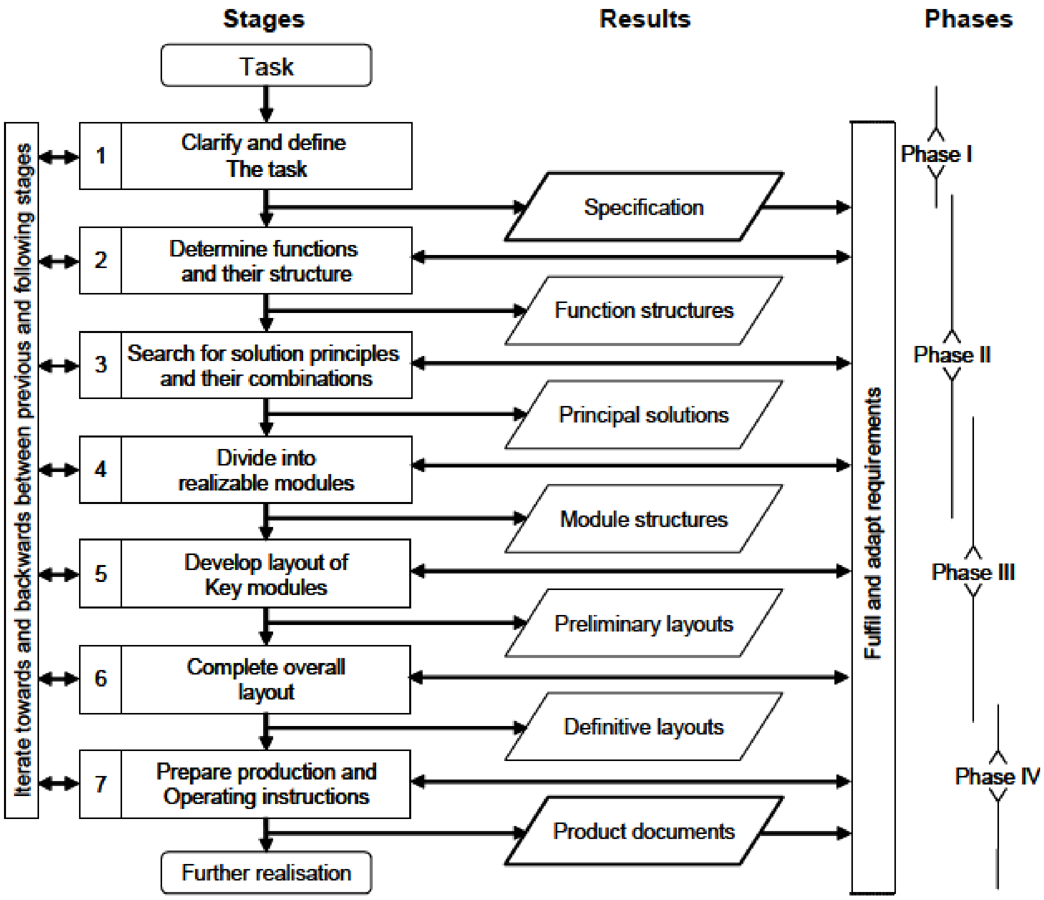


Figure 4.1: Guideline VDI 2221 [JB06]

To understand better the seven steps, the explanation of each step with his purpose is shown:

- Step 1 is necessary to clarify the design task and to derive requirements. This step is marked by the collection of a huge amount of information and the identification of information gaps. The result of this step is a structured list of all requirements, which is the basis for the following steps.
- In Step 2 the functions of the product must be defined. Starting with the entire function of the product, all sub functions which the product has to fulfil must be analysed. Results are one or more function-structures, giving an overview about the functions and their internal, logical connections.
- Step 3 involves searching for solutions for important sub-functions. The solutions for the different sub-functions must be combined into overall solutions, the result of that step.
- In Step 4 the overall-solutions are structured into realisable modules. The modules have to be made concrete by adding information about materials, geometry and other parameters.
- Steps 5-7 arrange the very high expenditure phase of embodiment of the product into several steps.

A characteristic of all the steps is that several solutions are generated, analysed and evaluated at the same time. The decision for one solution is based on the collected and documented information of the design process. The solutions of the conceptual phase are normally stored in the designer's brain because data-management is not widely distributed in that phase. These solutions are lost for later projects [SKW03].

5 Identification of boundary conditions and requirements

At the beginning of this chapter, the technical system will be described. As defined in previous chapters, the main challenge is the development of a device for overcoming centrifugal force in rotational areas of passing projectile, able to position the projectile correctly and smoothly for the initiation of next weft insertion at target speeds. The final part of the chapter will be composed of a detailed list of requirements.

5.1 Description of the technical system

In the following, the description of relevant structures and components, the distances and spacing between parts will be exposed. The description of boundary conditions and forces will be exposed, to obtain a list of requirements.

5.1.1 Relevant distances and components

The technical system comprises all parts of the actual demonstrator. Fig. 5.1 shows an overview of the demonstrator structure. The demonstrator comprises a weaving machine and a module for weft insertion. The position of the different elements and the parts in motion are shown.

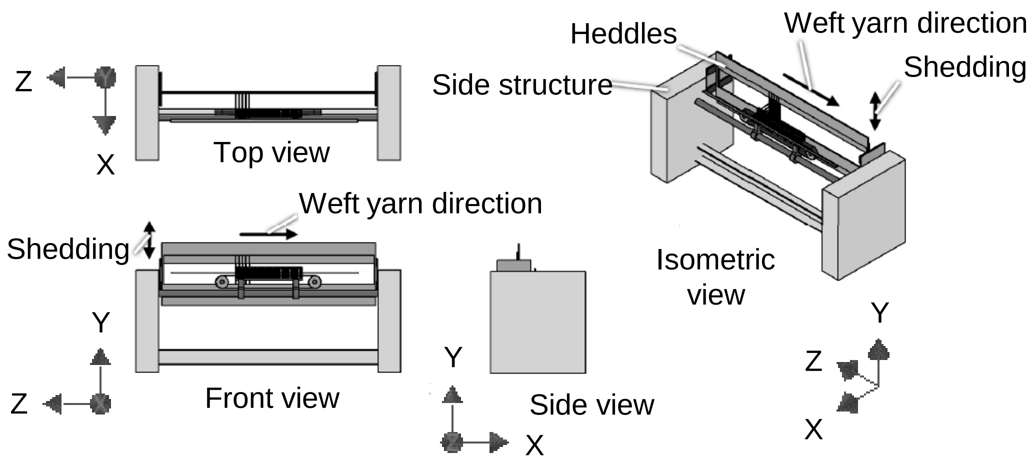


Fig. 5.1: Demonstrator structure [Lam16]

The relevant parts of the structure are the belt, projectile, magnets, pulleys, reed and the magnet holder. Side structures and other parts of the machine frame also have to be taken into account to avoid collisions.

In the following, the weft insertion module is shown (Fig. 5.3). The reed movement is synchronised with the projectile position. The reed structure movement is done due to the axis rotation. The short distance between axis and pulley restrict the width for a rotational part to be installed in the middle. This distance will be shown in detail later.

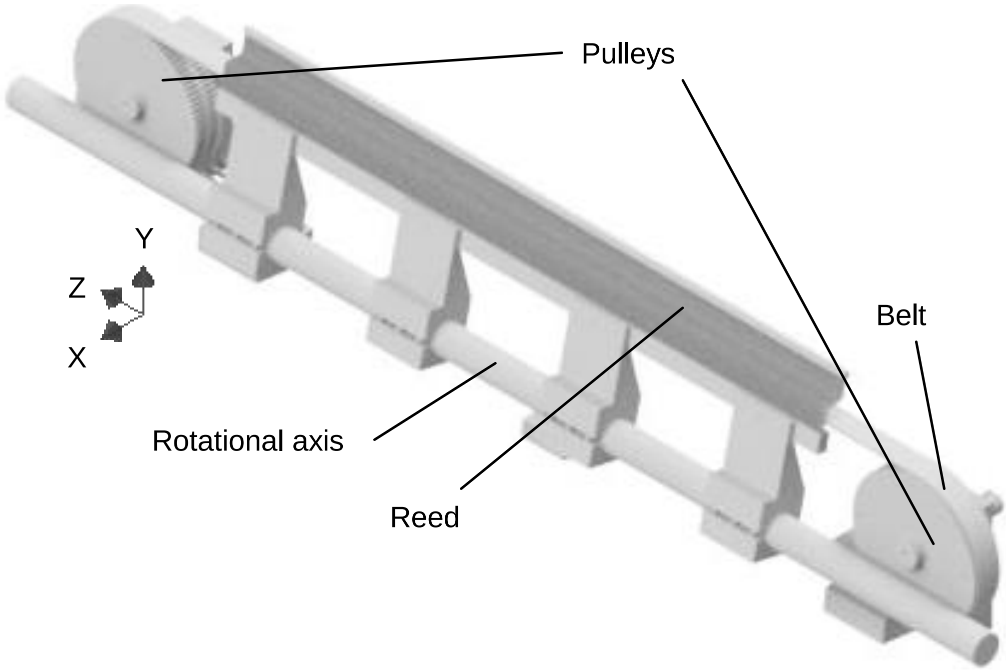


Fig. 5.2: Module of weft insertion

To describe the pulleys and the timing belt, the commercial features follows:

- Pulleys:
    - Brand: MADLER
    - Model: HTD 8M
    - Material: Phosphated grey cast iron GG30
    - Number of teeth: 90 teethes
- Timing belt:
    - Belt width: 30mm
    - Model: “8M RPP 2520 Lw 30 mm - Zähne: 315 - 2520-RPP-8-30”.

Due to the pulleys rotation, the timing belt moves linearly between both pulleys. The timing belt has been modified to attach the magnetic holder. Basic timing belt, pulley dimensions and the magnet holder structure are shown in Fig. 5.3.

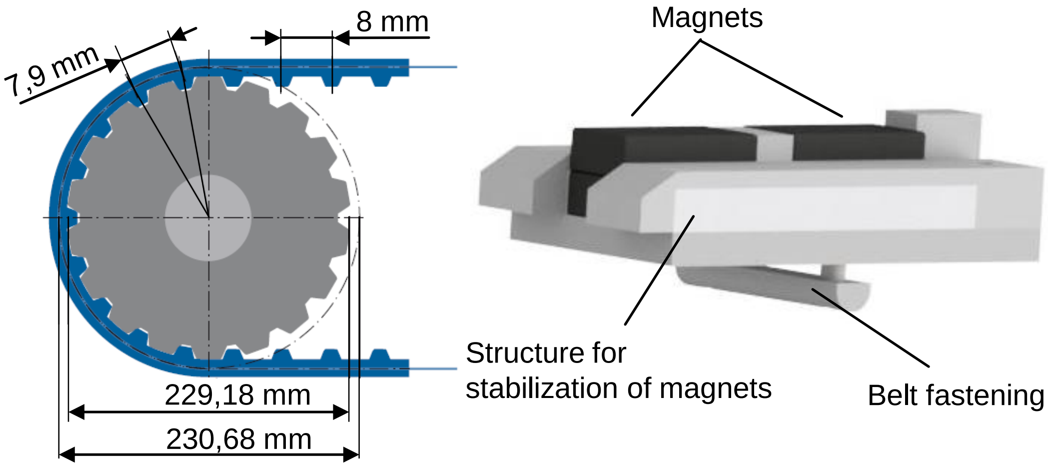


Fig. 5.3: Belt and pulley on left side [Str14] and magnetic holder on the right

The timing belt and the pulley have been selected to ensure an exact ratio R. Ratio R is calculated dividing how many pulley revolutions are needed to fulfil a full belt travel. This means that a complete rotation of the belt is repeated each 5 pulley revolutions.

The current projectile design is shown in Fig. 5.4. Two magnets are integrated into the projectile with the correct alignment with the previously defined magnet holder attached on the belt. The selected magnets are manufactured by HKCM Engineering e.K. The type of magnet is labelled as “Magnet-Cuboid Q05x04x01.5Ni-YXG30H”.

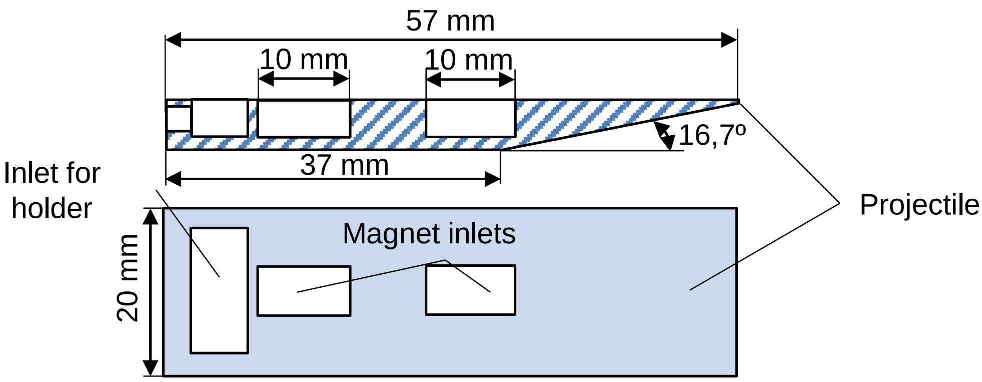


Fig. 5.4: Projectile dimensions

Considering the yarn holder, the projectile structure and also the magnets, the mass centre is considered to be separated 10 mm from the bottom surface. The projectile mass considered is 14 g.

As the most relevant parts have been described, measurement of distances follows.

5.1.2 Relevant distances and space available between parts

Space restrictions is a crucial parameter in the device design. Therefore, all relevant dimensions must be identify as a start-up point in order to take advantage of the space opportunities. A desired requirement is to develop a device with the smallest possible dimensions.

The distance in the “y” axis direction between the top surface of the pulley and the reed define the distance that the projectile has to be lifted. The distance in the “z” axis between the pulley top position and the edge of the reed define the projectile trajectory. To calculate the exact centrifugal force, the rotational axis distance from the pulley to the projectile centre of mass needs to be known. The space available between the magnet holder and the projectile is relevant to define the dimensions of possible parts to release the projectile from the magnet holder.

Fig. 5.5 shows relevant distances at the left side of the demonstrator.

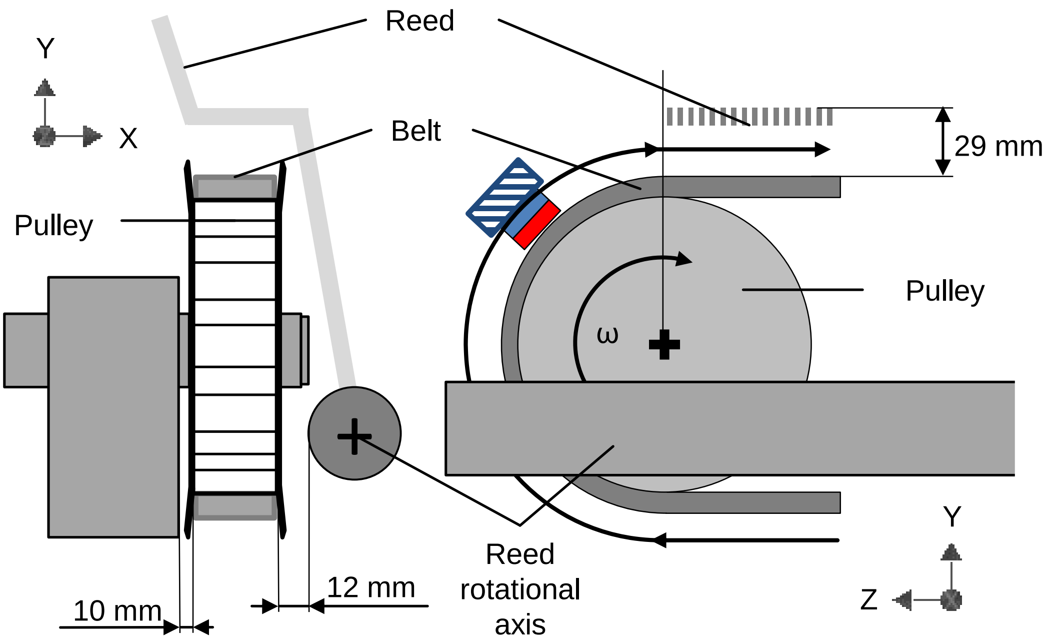


Fig. 5.5: Relevant distances of components on the left side of the demonstrator

To avoid collisions of the device which is to be developed in present thesis with any components of the current demonstrator, the device has to keep at least a minimum distance from all surrounding surfaces at any moment of passage.

Fig. 5.6 shows the relevant distances at the right side of the demonstrator. The reed rotational axis blocks the projectile way during an interval of 30º angle of main shaft rotation. Due to the rotation of the axis, the projectile travels without collision around the pulley. A fixed part attached to the pulley will cross this way five times each cycle so four of five of the times will crash with the reed rotational axis.

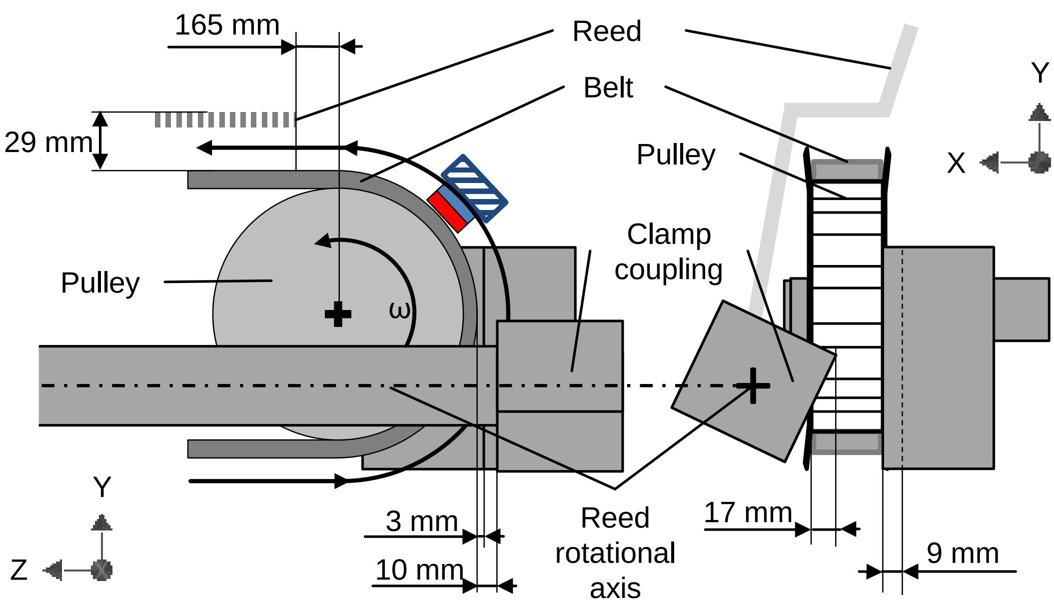


Fig. 5.6: Right side relevant distances

The distances between magnet holder and projectile are shown in Fig. 5.7. These distances are fundamental to develop a part able to hold, catch and release the projectile with mechanical parts applying pressure at the functional surfaces of the projectile. These distances define the maximum thickness of a part to be positioned in the middle of both and its shape to apply force correctly.

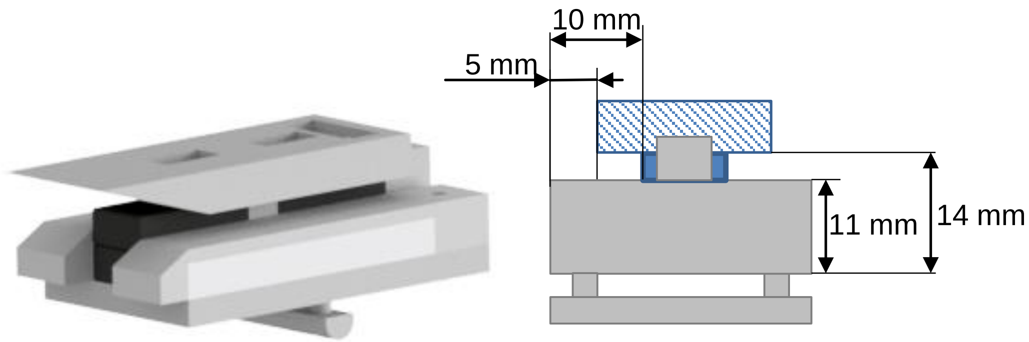


Fig. 5.7: Structure and distances between magnet holder and projectile

5.1.3 Projectile velocity

The projectile speed is fundamental to define the motion of the parts involved. The starting point to determine the projectile speed, is the desired production rate. T_s is defined as the time needed to fulfil a complete cycle. This cycle is composed of the time for a complete weft insertion and the rest of the functions to produce the fabric. To achieve a production rate of n = 1200 insertions/min, T_s is obtained with Eq. (5.1). A value of T_s =

0,05 s/insertion is obtained. The following method for calculating the necessary projectile velocity is also described in [Gol15].

$$T_s = \frac{1}{n} \tag{5.1}$$

As mentioned above, T_s does not only include the weft insertion time. Part of the time is required for the edge formation, change of weft yarn, beat-up and shedding. This time component is called the rest time $T_{r.}$ It depends on the weft insertion method. In the case of the magnetic weft insertion, it depends on the ratio of the total belt length to the weaving width but also from time for shedding and reed-beat-up. However, the overall belt length for a weave width of 1,9 m has not yet been set. For a guideline, the approximate rest periods of different types of weft insertion is shown in Tab. 5.1.

The absolute rest time can be calculated using the following formula:

$$T_r = \frac{1}{n} * p \tag{5.2}$$

Meaning of p: Rest period in %

Tab. 5.1: Rest periods of different weaving types and their mean value [Ada01, GrV14]

Weft insertion type	*Rest period in %*	*Production in Insertions/min*	*Absolute rest time in s*
Projectile weaving	*36*	*800*	*0,027*
Rapier weaving	*30*	*750*	*0,024*
Air-jet weaving	*55*	*1500*	*0,022*

If the absolute resting times of the different weaving methods are averaged, a value of T_r = 0.024 s is obtained. Thus, the projectile will travel the reed in 0.026 s. The velocity V_{pr} is calculated with Eq (5.3). With a value of 1.9 m for the weave width, a velocity V_{pr} of 73,1 m/s is obtained [Gol15]. For a weaving width of 1 m, only 50% of this speed would be required. [Str14].

$$T_{pr} = \frac{b}{T_s} \tag{5.3}$$

This velocity is one of the fundamental requirements.

5.1.4 Centrifugal force

At the following subchapter, the quantification of the centrifugal force is made. The most relevant parameters are defined with the explanation of the commercial parts installed in the demonstrator and the projectile velocity defined at the previous subchapters. In Fig. 5.8, the return of the projectile is considered.

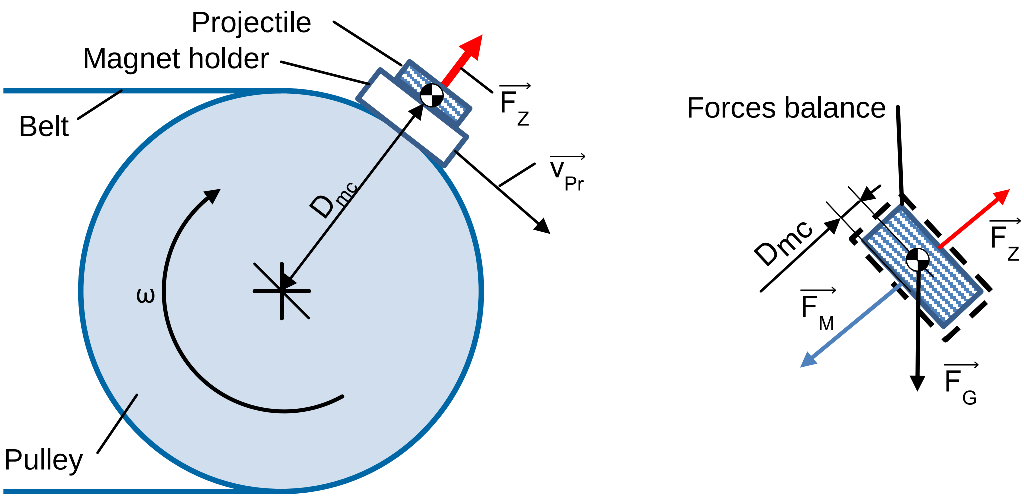


Fig. 5.8: Forces balance in the projectile

The most important parameters to calculate the centrifugal force applied to the projectile are:

- Distance between the rotational axis and the projectile mass centre
- Projectile velocity
- Projectile mass

In the previous subchapters, the projectile speed and the projectile mass have been defined. To define the distance between the rotational axis and the mass centre of the projectile D_{mc} three more distances need to be defined.

R_{rs} is the distance between the pulley rotational axis and the external belt surface. D_{mh} is the magnet holder width. D_{mp} is the distance between the bottom surface of the projectile and his mass centre. D_{mc} is calculated adding up all the distances previously defined as shown in Eq. (5.4)

$$D_{mc} = R_{rs} + D_{mh} + D_{mp} = 115{,}09\text{ mm} + 14\text{ mm} + 9\text{ mm} = 138{,}09\text{ mm} \tag{5.4}$$

This results in Eq. (5.5), the following relationship to calculate the centrifugal force:

$$F_z = m_{pr} \cdot \omega^2 \cdot D_{mc} = m_{pr} \cdot \frac{(v_{pr} \cdot D_{mc})^2}{D_{mc}} = m_{pr} \cdot \frac{v_{pr}^2}{D_{mc}} \tag{5.5}$$

With the assumptions of mass and velocity of the projectile and the distance between the rotation centre and the projectile mass centre, the centrifugal force acting on the projectile calculated is:

$$F_z = 14 \cdot 10^{-3}\text{kg} \cdot \frac{\left(73{,}1\frac{\text{m}}{\text{s}}\right)^2}{138{,}59 \cdot 10^{-3}\ \text{m}} \approx 540\ \text{N} \quad (5.6)$$

5.1.5 Magnet force definition

The centrifugal force is the highest force applied on the projectile during the full cycle of weft insertion. The effect of other forces involved are minimum compared with the centrifugal force as detailed in [Gol15]. The complete set of forces applied on the projectile during the weft insertion are shown in Fig. 5.9.

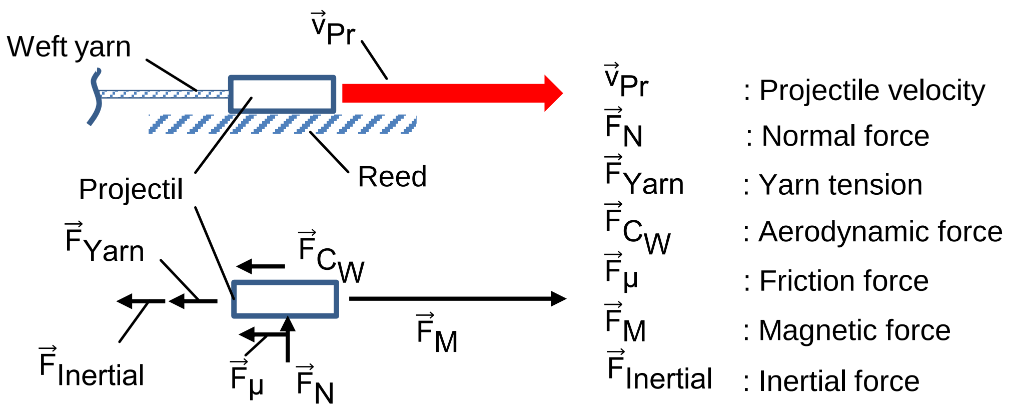


Fig. 5.9: Projectile forces balance

The effect of the gravity force is maximum at the bottom part of the pulley, added to the centrifugal force. This force is less than 1 N and it is neglected, as the centrifugal force is more than 500 N.

The friction force is present due to the contact between reed and projectile during the weft insertion [Str14]. The higher is the magnetic force between projectile and magnet holder, the higher is the friction force between projectile and reed. Currently, this force is planning to be supressed by the development of a new flying projectile. At this work the friction force is assumed to be zero as no contact between reed and projectile is present.

Aerodynamic force is the base to the projectile develop before mentioned. After testing the projectile, is not relevant compared to the centrifugal force. Is assumed to be null [Kes17].

Due to the desired requirement of minimum weight of the magnet holder and projectile, the use of a set of magnets, granting a force of more than 540 N is not a suitable solution. In [Gol15] a set-up of magnets is described, which induces a magnetic force of maximum 94,3 N. The solution described in [Gol15] does additionally not comprise the function of lifting the projectile.

As explained before, the most relevant force is the centrifugal force and it only acts at both pulleys. The purpose of this work is to counter this force at both pulleys. Therefore, reduce the magnetic force to the minimum at which yarn transport still carried out safety is the main challenge. Thus, the magnet force will be assumed to be null. If the developed device is able to counter all this centrifugal force at both pulleys, the presence of magnet force would be a benefit to make it safer.

5.1.6 Specific requirements

At the present moment, the advanced project stage marks specific requirements to be fulfilled. The desire to achieve the optimal demonstrator working regime have resulted in several tested parts, modifications and corrections. Due to the experience since the beginning of the project, to develop a new device, some restrictions are present. The most important restrictions are:

- Avoid friction contact between projectile and static parts of the new device due to the projectile movement
- Device without electronical parts
- A minimum of modifications to the current system
- Mechanical device to ensure a correct synchronism between parts
- No use of air pressure

This specific requirements limit options to fulfil the task and there are the base to develop a device to perform all functions.

5.2 Requirements list

The requirements list summarizes all previously determined boundary conditions and specifications. Previous works [Kem14, Gol15, Str14] and the current demonstrator state are important for the design process and are taken into account to make the requirements list. The requirements are classified according to obligatory (O) or desired (D). Objectives which must be fulfilled under all circumstances are considered as obligatory. If a solution does not accomplish one of these requirements, the idea cannot be pursued further. Objectives that are classified as desire do not lead directly to the exclusion of a solution option, if the option does not meet the desired request. The complete list of requirements is shown in Tab. 5.2. It serves as basis for all further construction steps.

Tab. 5.2: Requirements list

F/W	Requirements
	1. Geometry
D	Small installation space
O	Compact design of moving parts to minimize the inertial forces
O	Keep the maximum available space available
D	Mechanical device
O	Avoid collisions
O	Reduce modifications of the basic weaving machine to minimum
	2. Kinematics
O	Able to rise the projectile to the high of the reed
O	Synchronous movement with timing belt
D	Safe passing of projectile on pulley
O/D	Insertions/min: 400 ins/min (O); 1000 ins/min (D)
D	Optimal trajectory passing of projectile on pulley to minimize oscillation
D	Not controlled by electronical devices
O/D	Max projectile velocity: 50 m/s (O); 75 m/s (D)
	3. Forces
O	Minimizing the moving masses
O	Minimization of friction forces
O/D	Centrifugal force to be overcome: 200 N (O); 500 N (D)
D	Minimize vibrations
D	Magnet force between magnet holder and projectile: 1 N (D)
	4. Power
O	Only mechanical power
O	Without external power
D	Minimum energy consumption
D	If power conversion, max performance

F/W	Requirements
	5. Materials
D	Do not use a ferromagnetic material
D	Use of low-mass materials
O	Use of existing materials
	6. Safety
D	Prevent manual intervention on motion parts
	7. Maintenance
D	Maintenance-free
D	Good accessibility of the components
D	High maintenance intervals
	8. Use
D	Without electronically controlled movement
D	Operating time of at least 20000 h
D	Low noise
	9. Manufacturing:
O	If possible, use standard and purchased parts
O	Production in institute workshop
	10. Installation
O	Assembly at ITA
D	Easy assembly and disassembly
	11. Costs
O	Minimum costs

5.3 Conclusion

At the beginning of this chapter, the task was formulated for the definition of the new device purpose. As a result, the task is to develop a new device which makes it possible to utilize the full potential of the magnetic weft insertion. Subsequently, the requirements and boundary conditions for the new device were defined and specified. At the end of the chapter, a list of requirements was detailed with all requirements.

6 Determination of functions and their structure

In the following chapter, the functional structure of the new device will be determinate. The objective to make a functional structure is to abstract a technical task into functions and sub functions. At the beginning, the general function of fabric production will be shown, next the relevant sub functions in this work will be explained.

The main benefit of the function structure is reduce the complexity of a multipart problem into several problems more simple. During the design process, the resulting functional structure facilitates the identification of principle solutions to fulfil the separated functions with physical mechanisms, since the subdivision of the task reduces its complexity. The principal solutions to fulfil the separated functions will be discussed in the next chapter. To determinate the functional structure, there are a variety of different display options. To modulate the consecutive functions, a block diagram will be drawn. The main result is the material flow in the system. Substances, energy and signals can enter and leave the system [Tre91]. Signals designate controls, pulses and information. The overall function of the weaving process is the production of fabric. For this purpose, warp beams, spools with weft yarn, electrical energy and control signals are used in the system. In Fig. 6.1, the general function "fabric production" is shown.

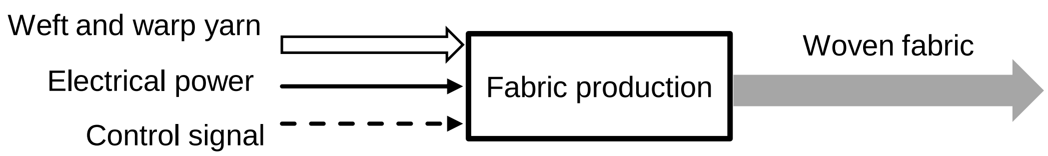


Fig. 6.1: General function structure of fabric production

Fig. 6.2 shows the general function "fabric production" with the required input variables. The input quantities are electrical power, control signal, warp and weft threads. The Output is the woven fabric. The general function "fabric production" can be divided into the seven sub-functions "weft presenting", "yarn transport", "projectile return", "edge formation", "shedding", "reed beat-up" and "fabric take-up". This subdivision is applied to weaving machines with a magnetic weft insertion. For reasons of overview, energy flows are not shown in Fig. 6.2. Furthermore, the signal flows were summarized under the designation "control signal". The entire process of fabric production and the subdivision of the general function into the seven sub functions are explained in [Kem14, Gol15]. To develop the new device, in the further process, only the partial functions relevant will be considered. These relevant functions will be exposed in this chapter.

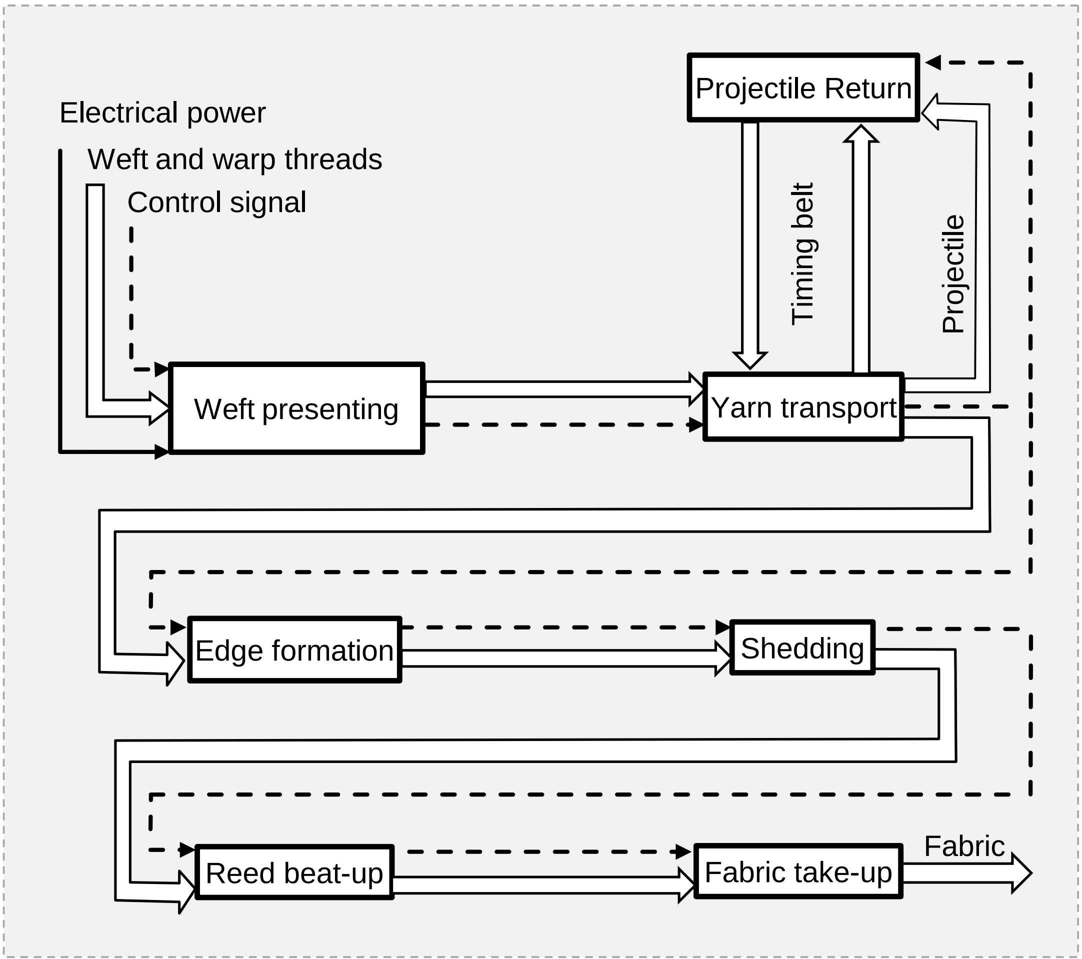


Fig. 6.2: Fabric production sub functions [Job16]

In Fig. 6.3, the projectile return function is detailed exposing all its sub functions in blocks. To define the function, projectile return its considerate to start with the projectile at the edge of the reed on right side and finish the function with the projectile at the edge of the reed at the left side. There is no electronical control signal, the projectile is moving due to the mechanical power of the belt being attached to the magnet holder or due to magnetic force without contact with the magnet holder, following the trajectories defined by the boundary conditions. The projectile and the forces are only inputs and outputs during all functions. The result of each function will result in a variation of projectile place or position.

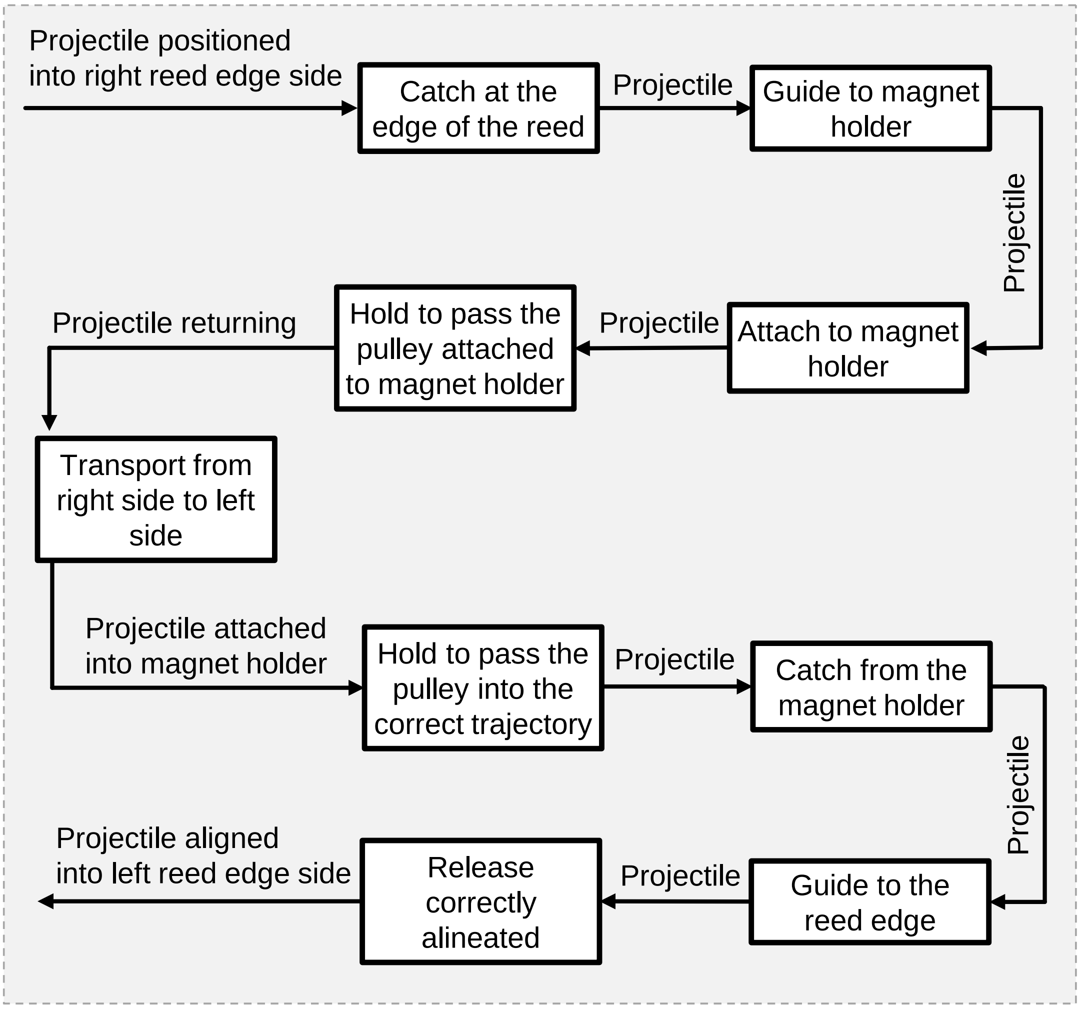


Fig. 6.3: Projectile return detailed function

At the present work, the projectile transport from right side to left side is not considered. This results in a clear function division between right and left side. At the right side, the projectile descends from the reed to the magnet holder without external force due to the magnetic force, therefore the following functions are not consider:

- Catch at the edge of the reed
- Guide to magnet holder
- Release into magnet holder

Finally, the function to fulfil at the right side is shown in Fig. 6.4.

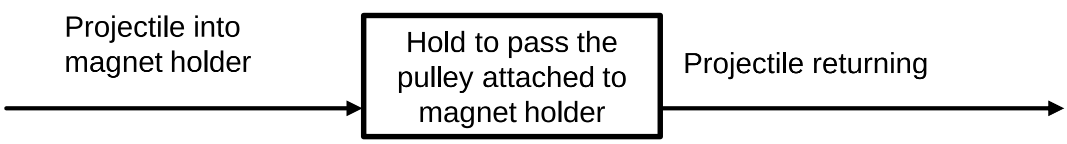


Fig. 6.4: Function to fulfil at the right side

The functions to fulfil at the left side are shown in Fig. 6.5.

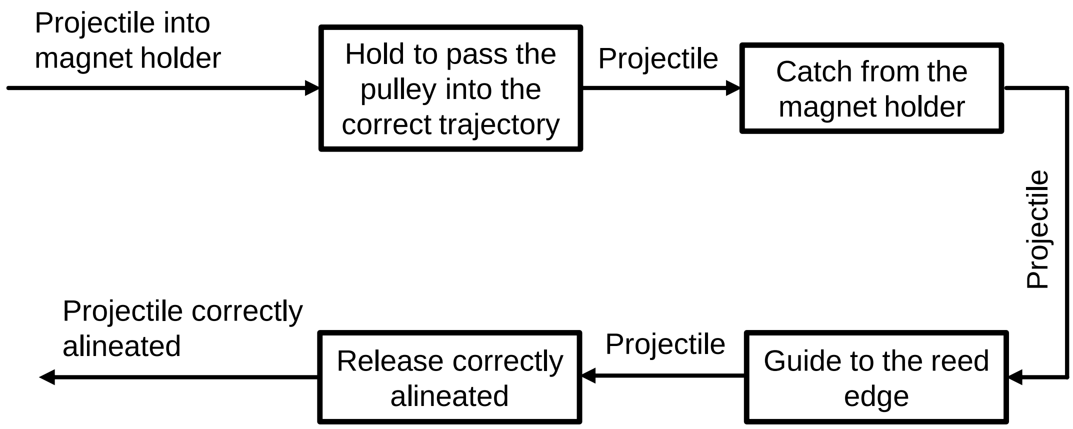


Fig. 6.5: Functions to fulfil at the left side

Since at the left side there are more functions to realize, the task is more complex and more detailed sub functions should be analysed. The movement of the holding device which is to be designed can be divided into two phases. The division in phase I and phase II is shown in Fig. 6.6. These phases are defined for an angular interval $\varphi = [0^o, 180^o]$ and $\varphi = [180^o, 360^o]$.

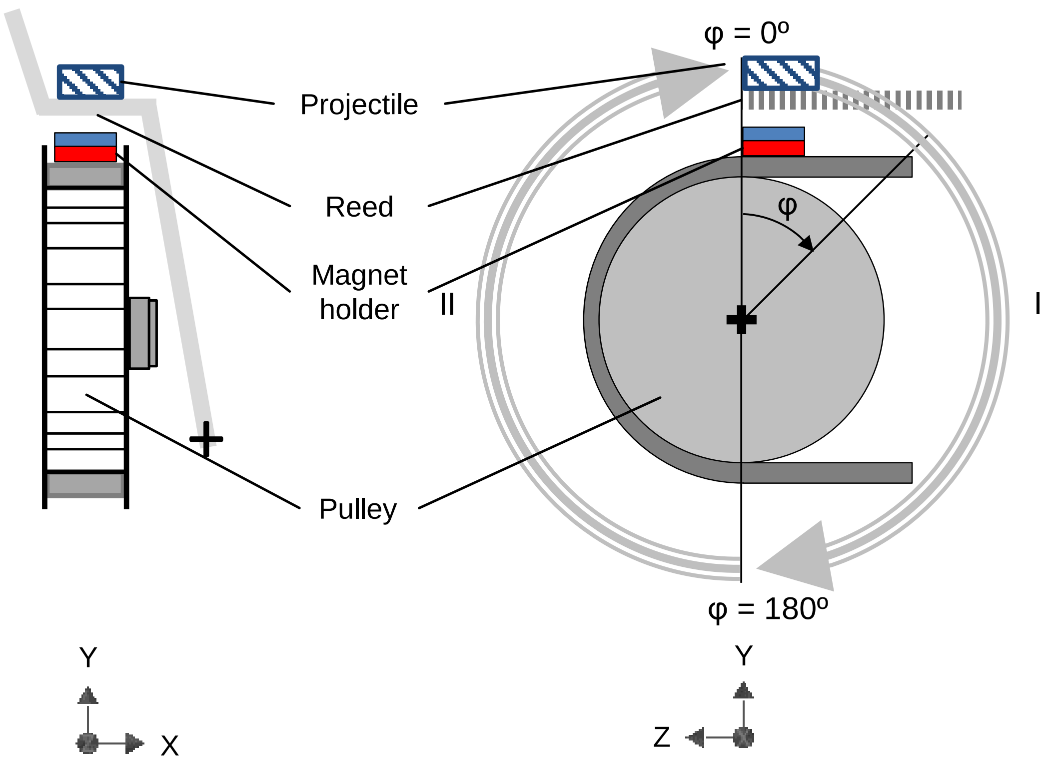


Fig. 6.6: Phases of movement as function of angle φ

Block diagram shown in Fig. 6.5 supports an overview of projectile flow but these functions can be defined with more detail and a set of functions can be fulfilled at the same time. Fig. 6.7 shows the function division before exposed divided into phases. This division supports to recognize the number of sub functions identical between different functions.

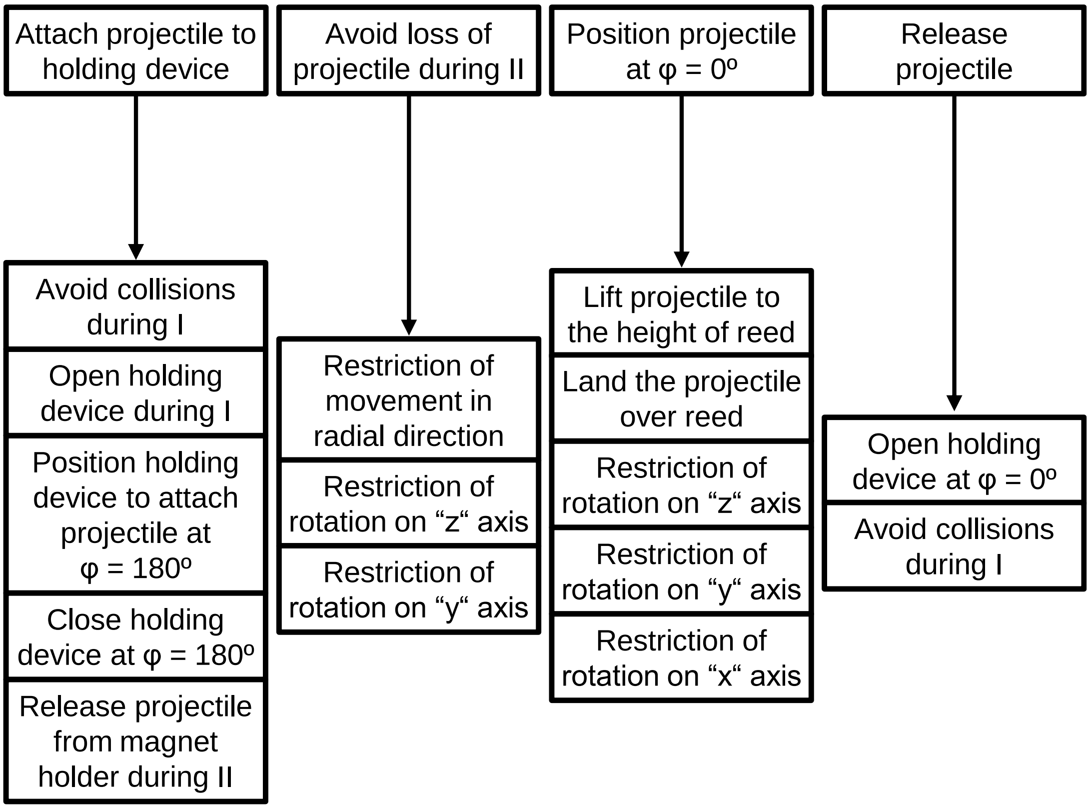


Fig. 6.7: Final functional structure of the left side

6.1 Conclusion

In this chapter, the functional structure required for this work was presented. For this purpose, the functional structure of an entire process of weft insertion was first considered. In several steps, the partial functions relevant for this work were subdivided into further sub-functions. At the end of this chapter, a final functional structure with the relevant sub-functions is suggested for the passage of the projectile on the insertion side (left side). This functional structure is used for a successive development of principal concepts at the next chapter.

7 Concept development

In the following chapter, concepts to fulfil the functions and sub functions explained in the previous chapter will be defined. The challenge is to define concepts to fulfil all the sub functions and combine these functions to be carried out simultaneously by the same device. At the beginning, ideal concepts to solve the main sub-functions will be carried out. This ideal concepts will be characterized by simplified forces applied to the projectile. Next, mechanical restrictions to materialize these concepts and possible projectile trajectories will be explained.

7.1 Concept development of the main functions

To describe concepts to fulfil all the sub-functions, main sub-functions will be defined first. The remaining sub functions will be fulfilled with partial modifications of the concepts to satisfy the principal functions as shown in Fig. 7.1.

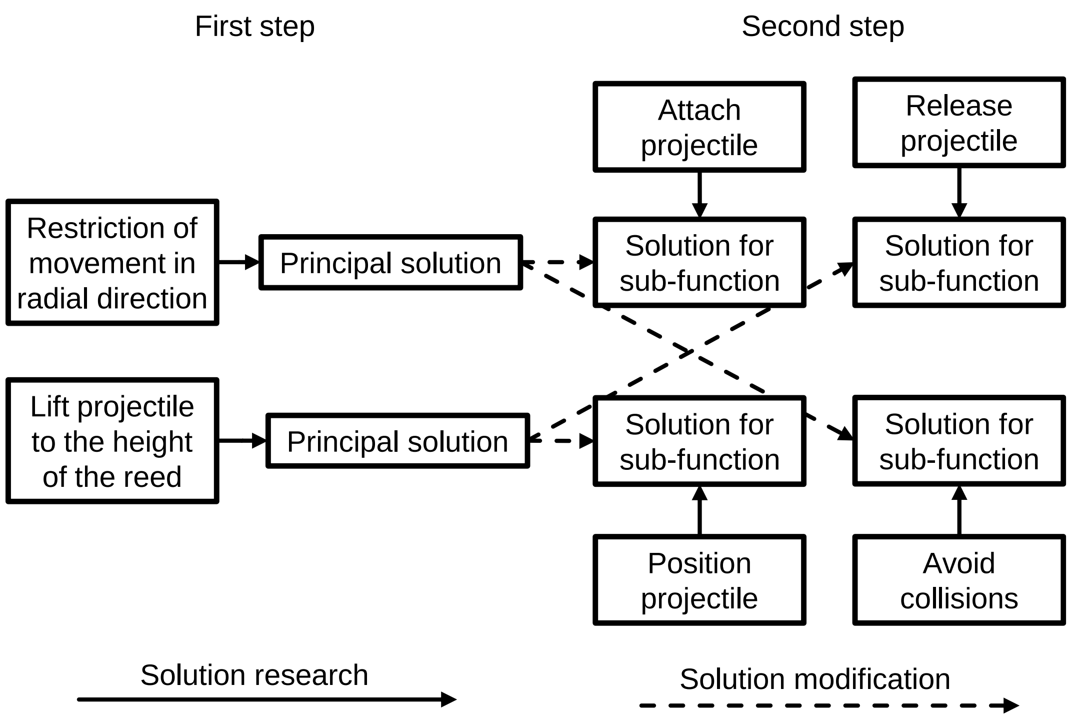


Fig. 7.1: Steps of the concept development

The restriction of movement in radial direction and the elevation of the projectile are the principal sub-functions.

7.1.1 Restriction of movement in radial direction

To avoid the loss of the projectile during the trajectory II (Fig. 6.6), an accurate balance of forces around the projectile is needed. The application of the necessary forces to the projectile to counter the present forces will guide the projectile into the desired trajectory. The present forces have been studied in previous chapters (Fig. 3.1). The necessary forces to achieve the right balance can be either surface or body forces. Fig. 7.2 shows the different options to restrict the movement in radial direction. Restriction of the movement in radial direction is the principal sub-function to avoid the loss of the projectile.

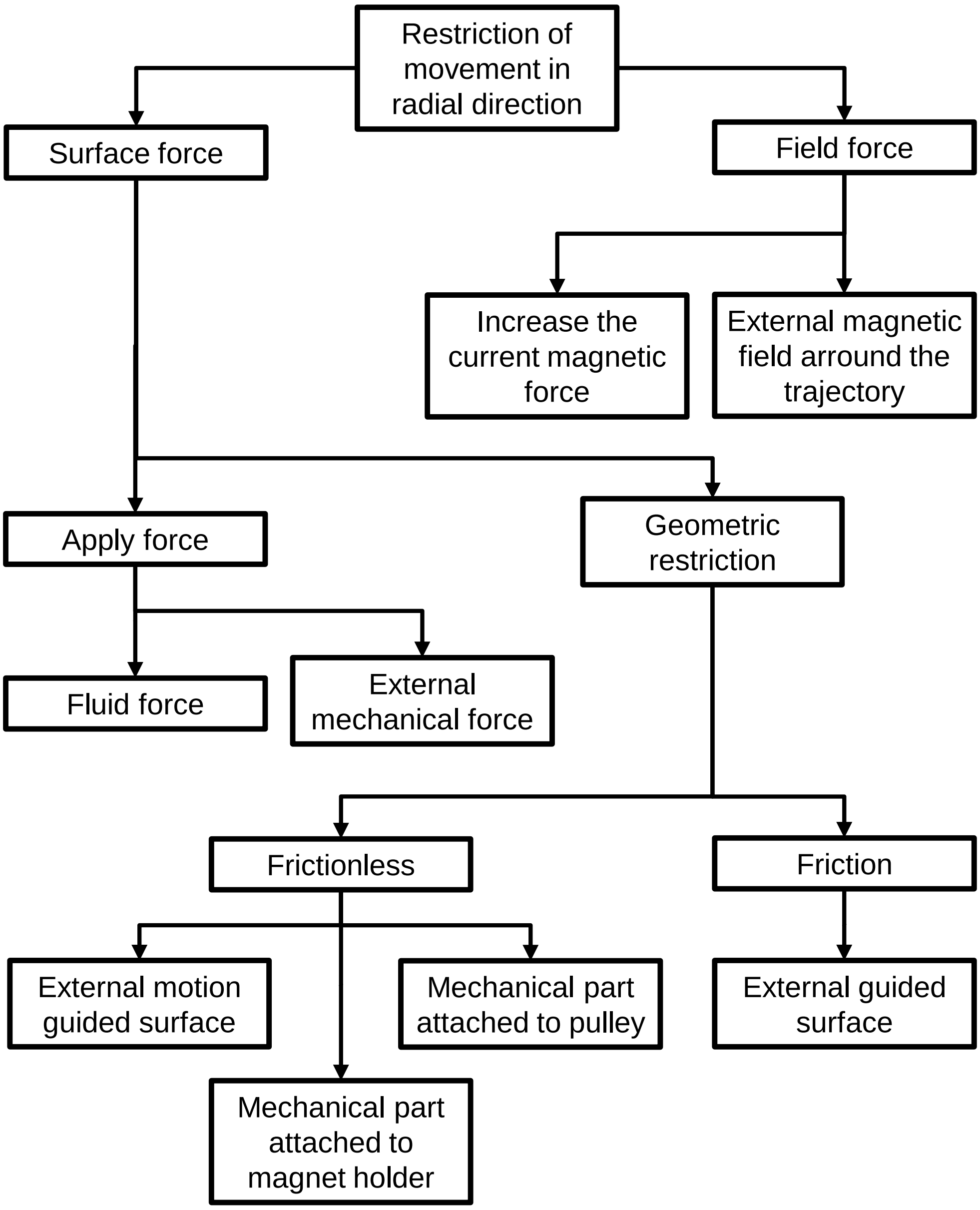


Fig. 7.2: Options to restrict the movement in the radial direction

Regarding body forces, the increase of the magnetic force between projectile and magnet holder has been studied in another project without satisfactory results in a holistic point of view as the function of lifting the projectile is not regarded [Gol15]. Currently, there is also ongoing research focusing on the external magnetic field around the projectile trajectory. No stable magnetic junction could be established.

Concerning surface forces, application of a fluid force is not considered in this work due to the evidently poor efficiency and the necessity for an external power source. Application of an external and mechanical force is neither considered due to the difficulty of synchronisation between both parts and struggle to apply it correctly.

Therefore the final option is to build a geometrical restriction around the external surface of the projectile. The construction of an external guided surface was one of the first ideas to avoid the loss of the projectile but the friction at high speed between projectile and guided surface result in wear and hence problems with dust formation [Str14].

A frictionless geometric restriction is choice as the best option after the evaluation of the previously options. A frictionless geometric restriction is the only option considered in this work. To build a frictionless geometric restriction, relative velocity at the contact surface between both bodies must be zero. Fig. 7.3 shows two options to equalise the velocity between both bodies at the contact surface. The motion of the projectile and the geometric restriction should have equal velocity, as shown on the left of Fig. 7.3. A rotational fixed roller, with linear speed at its edge equal to the projectile velocity, is displayed on the right of Fig. 7.3.

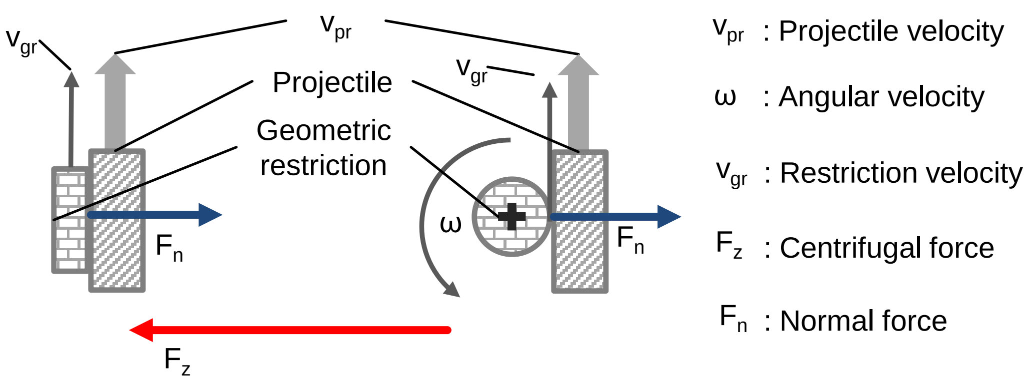


Fig. 7.3: Normal force between projectile and geometric restriction

Concerning the rotational fixed roller, to generate this force during the full projectile trajectory, issues arise. Due to the irregular surface of both bodies and its relative motion, the contact is not frictionless but the friction between bodies is reduced near zero. As shown in Fig. 7.4 a circular roller arrangement is needed to fulfil the desired trajectory. On the one hand, the higher the number of rollers in the trajectory the higher the accuracy of movement to be achieved. But on the other hand, an increase in the number of rollers used would require them to be smaller in size and as a result the arrangement is more fragile and difficult to construct. Furthermore with the decreasing radius of the roller, the pressure applied to the projectile increases, according to the laws of Hertz. This results in increased wear. This concept has already been explained in [CHC00].

To achieve a frictionless contact, the functional surface on the projectile, in this case, the top surface, must be complex due to the multiple contact points present during the circular trajectory. The actual “flying projectile” shape is the reason for its success, therefore, modifications to its top surface are not considered [Kes17]. Thus, the only suggestion to continue developing this concept is to add two auxiliary surfaces at both projectile sides to be guided through two of the circular roller arrangements, one at each side. Another option is to attach two rollers to the projectile, one at each side and replace the roller arrangement with a guide surface. Both variants increase width and complexity of the projectile, which is not desired.

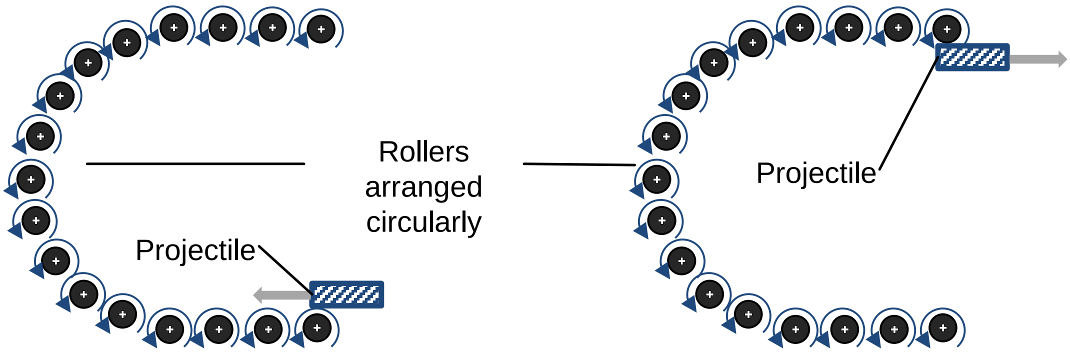


Fig. 7.4: Circular roller arrangement

The geometric restriction attached to the belt or magnet holder to maintain equal velocity with the projectile is now considered. From here on, this type of geometric restriction shown in Fig. 7.5, will be called a clamp. This clamp can actuate at the top surface of the projectile. Also, with a modification of the projectile sides it is possible to introduce the clamping part with two holes.

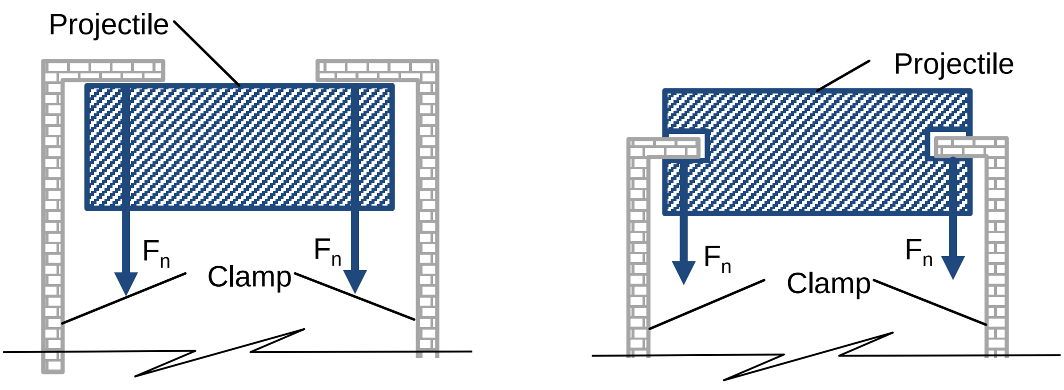


Fig. 7.5: Clamp to hold the projectile

Both solutions can fulfil the same task but with a different method.

7.1.2 Projectile raising to the reed´s edge

The main movement to position the projectile at the reed´s edge is to raise it from the magnet holder to the height of the reed. To carry out this movement, a force needs to be applied in the same direction as the centrifugal force. Fig. 7.6 shows two functional parts to apply the force and cause the linear movement to the projectile.

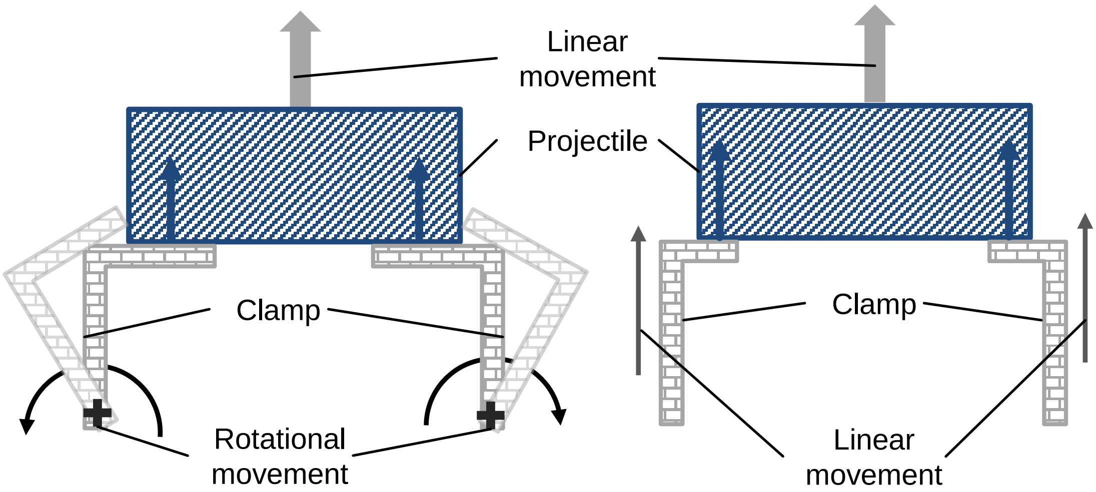


Fig. 7.6: Clamp to lift the projectile

To go over the desired trajectory around the pulley, a combination of circular trajectory and linear movement is needed. The circular movement of the projectile is present along the entire trajectory but the linear movement can be made at the beginning, during (trajectory A) or at the end (trajectory B) of the circular trajectory as shown at Fig. 7.7.

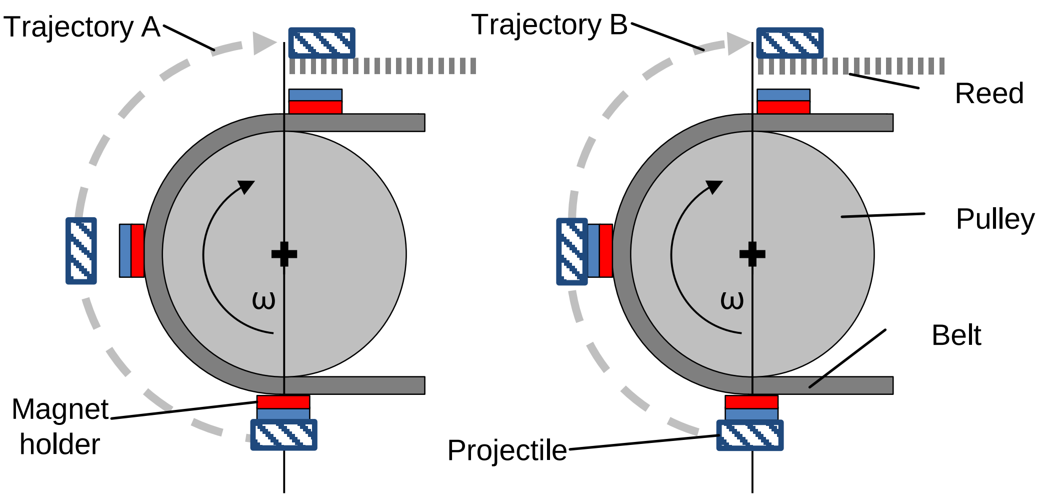


Fig. 7.7: Possible projectile trajectories around the pulley

8 Description of realizable modules

In the present chapter, realizable modules to fulfil the functions described at the chapter six will be explained. The concepts explained at the chapter seven will be used to develop these realizable modules. The description of the realizable modules will give an overview to identify the possible combinations of each module to fulfil the main function. At the beginning, a clamping device attached to the pulley will be explained. Subsequently, modifications to the basic design of the clamping device will be made to fulfil the different sub-functions. Finally, an external clamp driven by the pulley will be explained.

8.1 Concept I, clamping device attached to the pulley

To fulfil the basic function of holding the projectile, a clamping device is proposed. This clamping device is composed by a basic arm attached to the pulley with a clamp at its top. The basic concept is shown in Fig. 8.1. The basic arm is attached to the pulley alienated to the radial direction. This attachment ensures the correct synchronicity with the pulley motion. The clamp holds the projectile rotating around the entire trajectory actuating in the functional surfaces. The contact between clamp and projectile is frictionless because the relative velocity between both bodies is zero as before explained in Fig. 7.3.

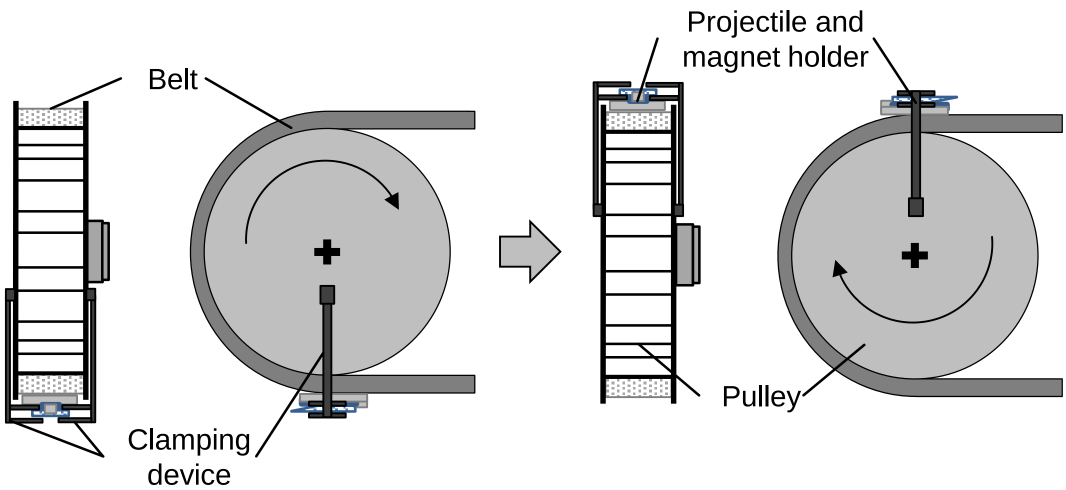


Fig. 8.1: Clamping device motion

In the following subchapters, the basic design of the clamping part it will be kept. However, additional parts will be added or modifications will be made to the basic arm or to the clamp to fulfil the different sub functions.

8.1.1 Concept IA, modification of the clamping device to lift the projectile

To hold and lift the projectile at the same time, two different options will be proposed. The movement to lift the projectile is possible because the clamping device is divided in two parts, clamping part and basic arm.

The first option (Concept IA1) is shown in Fig. 8.2. The arm is divided into two parts, the mobile arm and the fixed arm. The first part is fixed to the pulley and the second part is attached to the first part with a spring. Due to the union between both arms with the spring, the second part is able to travel in radial direction.

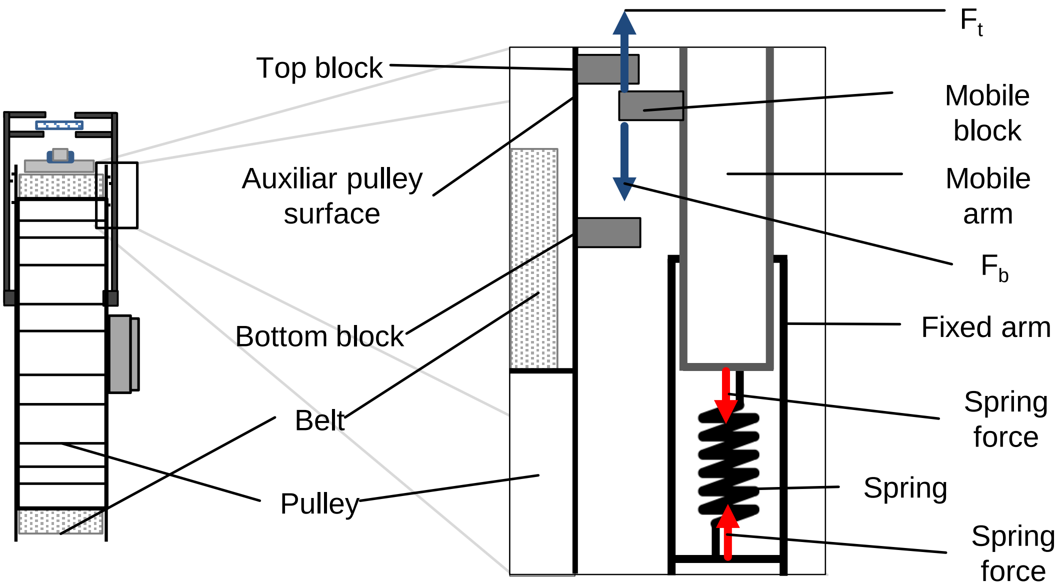


Fig. 8.2: Mobile arm with spring

The purpose of this design is to take advantage of the centrifugal force. The centrifugal force actuates on all the bodies attached to the pulley. The magnitude of the centrifugal force is proportional to the mass and to the distance between the body and the rotational axis of the pulley at constant velocity. When the clamp attaches the projectile, the mass of the top part of the clamping device will increase. The projectile attached to the clamping part will apply a radial force to stretch the spring and elevate it to the reed´s height. There are two blocks attached to the auxiliary surface of the pulley and one block attached to the mobile arm. The top block and the bottom block are attached to the auxiliary surface of the pulley. The mobile block is attached to the mobile arm. F_t is the force applied by the mobile block to the top block. F_b is the force applied from the mobile block to the bottom block. The distance between top block and bottom block is the distance needed to rise the projectile to the height of the reed. The combination of forces present in the mobile arm (F_{arm}) is shown in Eq. (8.1).

$$\sum F_{arm} = F_z + F_b - F_t - F_{spring} \tag{8.2}$$

$$F_z = m_{proj} * \omega^2 * D_{mc} + m_{arm} * \omega^2 * D_{arm} \tag{8.3}$$

$$F_{spring} = k * x \tag{8.4}$$

The F_{spring} is proportional to the constant k and the distance stretched or shrinking of the spring. F_z is the sum of the centrifugal force due to the rotational velocity (ω) of the projectile and the mobile arm. The mass of the projectile and the distance between the centre of mass of the projectile and the rotational axis (m_{proj} , D_{mc}) and the mass of the mobile arm and the distance between the centre of mass of the mobile arm and the rotational axis (m_{arm} , D_{arm}) will increase the centrifugal force. If the mobile block is in contact with the top block or the bottom block, the normal force F_b or F_t will compensate the centrifugal force and the spring force. If the mobile block is not in contact with the top block or the bottom block, the result of the forces will lead to an acceleration in the arm, moving the arm and the projectile attached into the clamp.

If the mobile block is in contact with the bottom block, then the clamping part is positioned to catch the projectile at the pulley bottom surface. If the mobile block is in contact with the top block, the clamping part is positioned to release the projectile at the reed´s edge. Calculating the spring correctly and positioning the blocks with accurate distances, four situations can occur depending on the position of the projectile.

- $\sum F_{arm} = 0$, $F_b > 0$: Projectile not attached.
- $\sum F_{arm} \neq 0$: Projectile attached and moving in radial direction.
- $\sum F_{arm} = 0$, $F_t > 0$: Projectile attached and positioned at the reed´s height.
- $\sum F_{arm} \neq 0$: Projectile release, arm moving in radial direction.

The position of the blocks is optimal if the length of the motion arm is reduced to minimize the mass of the second arm. If the mass of the second arm is much larger than the mass of the projectile, the effect of the mass of the projectile to stretch the spring will be smaller. The length of the second arm needs to be enough to ensure the correct stability between both arms. The main disadvantage of this concept is the motion of the arm at low speed. If pulley is rotating at lower speed than the normal speed, the centrifugal force due to the projectile is not enough to stretch the spring. To solve this problem, an additional device to ensure the correct positioning at low speed is needed.

The second option (Concept IA2) is based in the concept IA1 explained above. The basic structure of the concept IA1 is maintained but two parts are exchanged. The top and the bottom block are exchanged for a static guided part around the complete pulley perimeter which is in permanent contact with the top and the bottom surface of the mobile block. The basic design of concept IA1 is shown in Fig. 8.3.

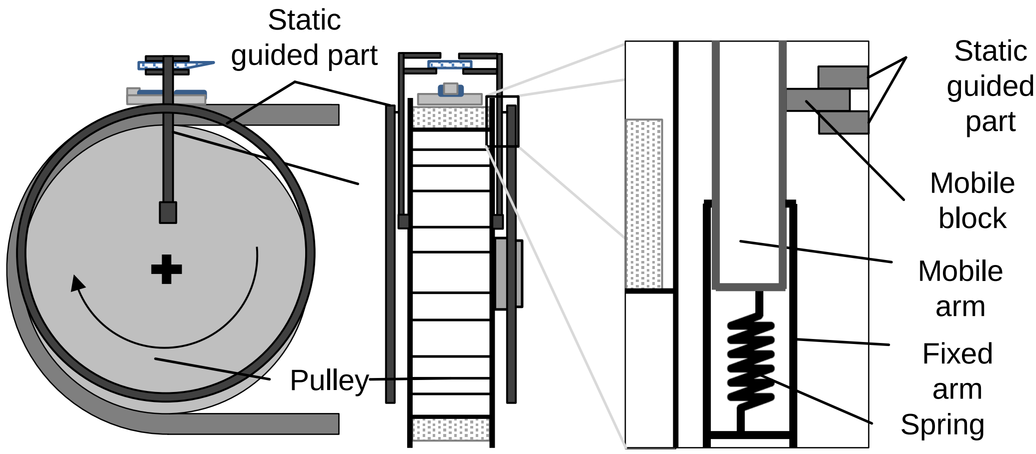


Fig. 8.3: Mobile arm with static guided part

This surface shall ensure the correct position of the clamping part during the entire trajectory even working at low speed. Nevertheless this modification results in a frictional contact between moving block and the guided part. The use of a magnetic tape to the guided part surfaces and the equipment of the mobile block with a permanent magnet with a correct arrangement of its poles could reduce the friction between both parts.

8.1.2 Modification of the clamping device for the attachment and release of the projectile (Concept IB)

For the attachment and release of the projectile, two different types of clamps will be exposed. In these concepts, the basic design of the arm attached to the pulley is maintained. The first design (Concept IB) is as shown in Fig. 8.4.

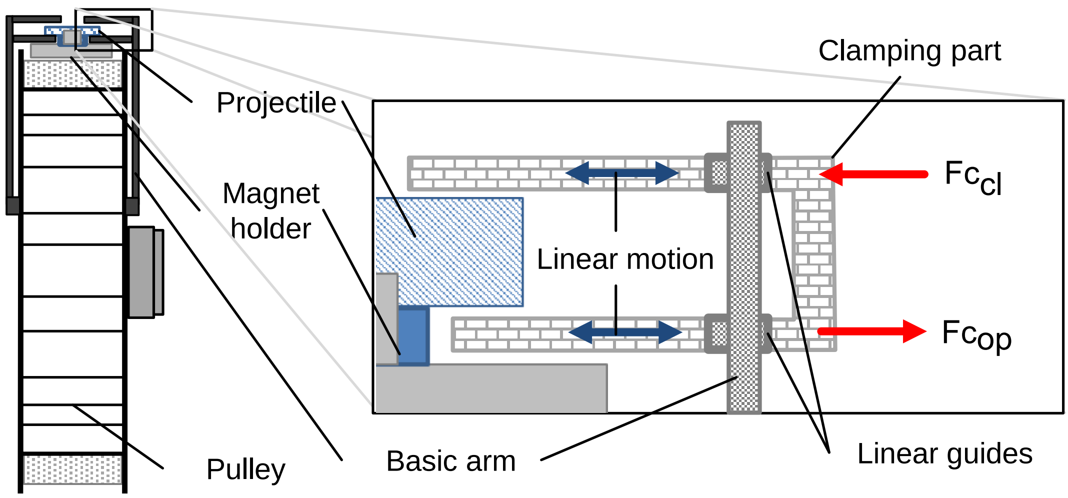


Fig. 8.4: Arm with mobile clamping part

The device is divided into two main parts, basic arm and clamp. The basic arm is attached to the pulley according to concept IA. The clamp is modified to hold two linear guides. With these linear guides, the clamping part is able to move linearly. The clamp holds the projectile by applying force to the functional surfaces. To release and attach the projectile, the clamp is displaced linearly. Due to this movement, the clamping device is able to attach the projectile at the bottom surface of the pulley and hold the projectile during the passage of the pulley. Also is able to open at the top surface of the pulley to release the projectile and avoid collision with the timing belt.

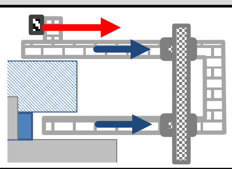
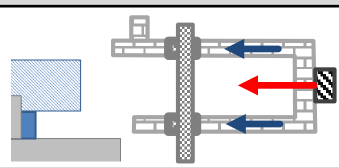
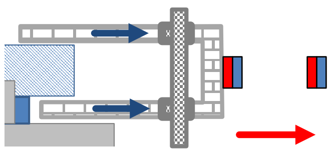
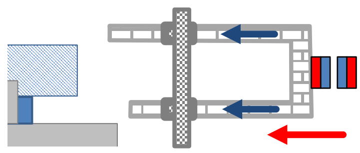
To induce the linear motion, a force in the direction of the linear motion needs to be applied to the clamp. The force to open the clamp needs to be in the opposite sense of the force to close the clamp. The system to initiate this force needs to be able to apply the force during the circular trajectory of the clamp due to the rotational movement of the complete clamping device. To initiate the force, three options are enumerated:

- Mechanical force
- Field force (permanent magnets)
- Geometric restriction

First option is to apply a mechanical force with an external part. A mechanical structure to initiate the force to close the clamping part is possible to develop at the sides of the pulley. The disadvantage of this structure is to apply the force to open the device. The space between clamping part and projectile limits the possibility of installing a motion part to apply the mechanical force. This force is discarded due to the necessity of an external power source, which requires a control unit and a respective software solution.

The systems to apply a field force or a geometric restriction are similar. Both systems need static structures to ensure the synchronicity with the projectile during the passage of the circular trajectory. Allocating the static structures around the circular trajectory described by the clamp, the force to cause the linear motion is applied progressively. This basic concept is shown in Tab. 8.1.

Tab. 8.1: Clamping part motion

Function / Concept	Open	Close
Geometric restriction		
Permanent magnets		

In the case of the geometric restriction (Concept B1), the force to open the clamping part is applied to an auxiliary surface at the top part. The force to close the clamp is applied at the right side surface. With the correct disposal of the geometric restriction, the correct movement of the clamp shall be ensured but the force initiation could be abrupt at high speed.

In the case of the field force (Concept B2), a magnet is attached to the right surface of the clamp. To open the clamp, another magnet is disposed to attract the magnet attached to the clamping part producing the force to open the clamp. To close the clamp, another magnet is disposed to repel the magnet attached to the clamping part producing the opposite force. This concept shall ensure a smooth movement of the clamping part but the magnet force needs to be strong enough at high speed to ensure the complete movement

The last option (Concept B3) exposed in this subchapter to open and close the mobile clamping part is shown in Fig. 8.5. This concept is based on a geometric restriction.

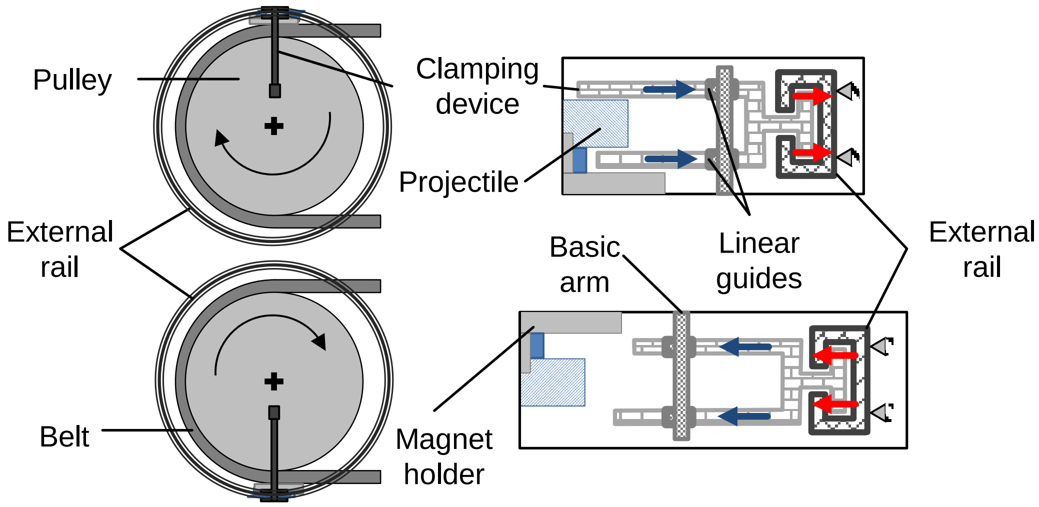


Fig. 8.5: Mobile clamping part with external rail as fixed guiding element

This external rail is disposed around the entire circular trajectory of the clamping part. The external shape of the external rail is a modified circle displaced in the perpendicular direction to the radius of the pulley the necessary distance to open the clamping part. Half external rail is more separated from the pulley (Phase I, Fig. 6.6). The transitions from the part more separated and the part more close is made at φ = 0 and φ = 180 (Fig. 6.6). The clamping part is modified with an auxiliary surface. This surface is introduced inside of the external rail. The internal part of the external rail is a geometric restriction which acts in both sides of the auxiliary surface. Hence a displacement of the clamping part in linear direction is induced. This design ensures that the clamping part is closed during the phase I and that it open during the phase II (Fig. 6.6).

The last design (Concept B4) to fulfil the functions hold, open and close is shown in Fig. 8.6. The basic arm is maintained and the clamping part is modified.

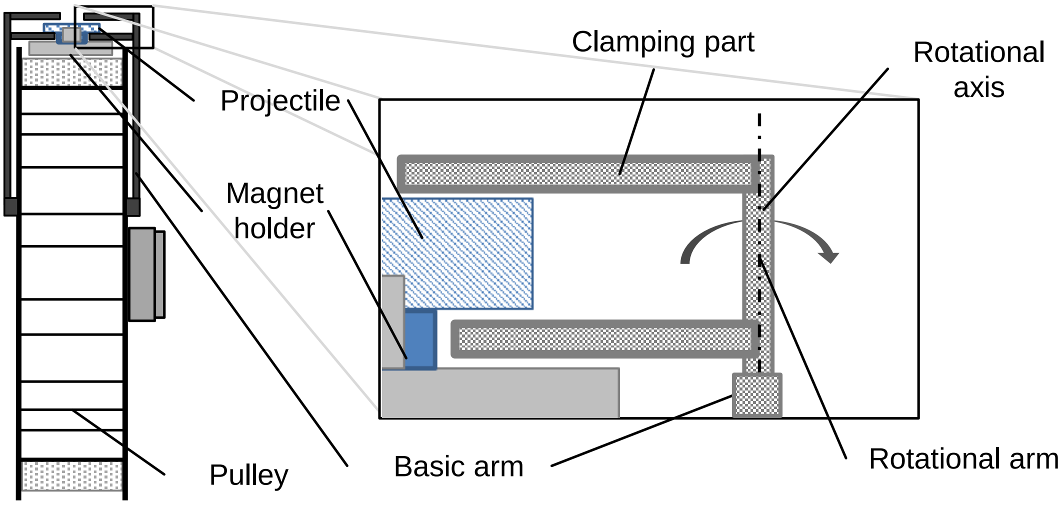


Fig. 8.6: Clamping device with rotational clamping part

The union between basic arm and rotational arm allows the clamping part to rotate 90º, attaching or releasing the projectile. This design requires less space to fulfil the function. The attachment of auxiliary surfaces to generate a force with geometrical restrictions or the use of a set of magnets are options to initiate the rotation.

8.2 Clamping device with external rotational axis (Concept II)

The main purpose to develop this device is to ensure the optimal trajectory of the projectile to lift it to the reed´s height. As explained in Fig. 7.7, to rise the projectile to the reed, a superposition of linear and circular movement is needed if the projectile go into the pulley (φ = 180) attached to the magnet holder. If the projectile is separated from the magnet holder before going into the pulley (φ = 180), travelling the correct circumference, the projectile can be lifted to the edge of the reed without linear movement. The circular movement is needed to pass around the pulley and the linear movement is needed to rise the projectile to the height of the reed. The circular movement is defined for an angular section and constant of 180º. The linear movement is defined by the height of the reed. This movement can be carried out during the entire trajectory. If the force to cause the linear movement is applied suddenly, the instability of the projectile positioning and the vibrations of the system will increase. Therefore, instead of causing the linear movement just at the beginning or at the final of the trajectory, the optimal option is to apply the force smoothly around the entire trajectory. The desired trajectory to lift the projectile to the edge of the reed is shown in Fig. 8.7.

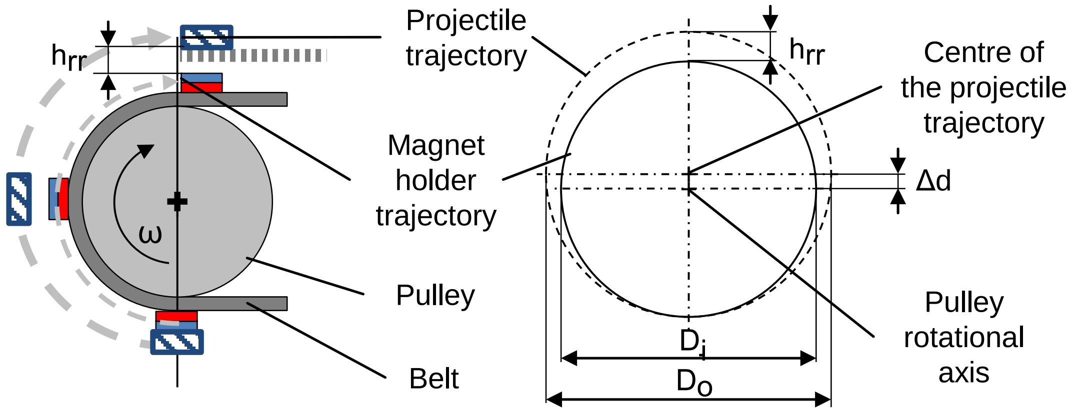


Fig. 8.7: Projectile trajectory with displaced rotational axis

The distance to rise the projectile from the top surface of the magnet holder to the reed (h_{rr}) is 15 mm. The diameter of the circumference which describe the projectile trajectory (D_o) is 15 mm larger than the diameter of the circumference which describe the magnet holder trajectory (D_i = 258 mm). The distance between both rotational axis (Δd) is 7,5 mm ($h_{rr}/2$). Therefore, a clamping device rotating with its axis in the centre of the projectile trajectory described before with an arm of 136,5 mm ($D_o/2$), is able to attach the projectile just at the bottom surface of the pulley and release the projectile just at the edge of the reed. The basic structure is shown in Fig. 8.8.

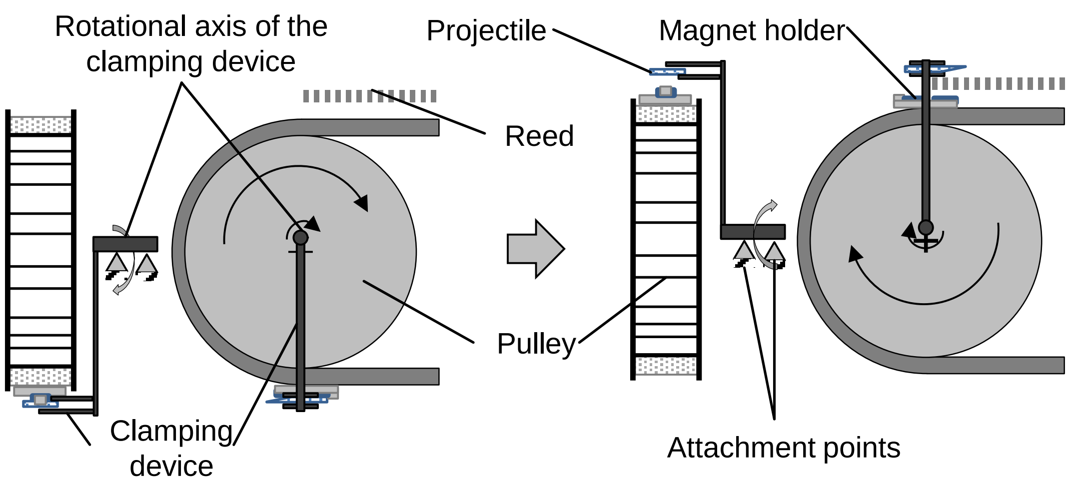


Fig. 8.8: Clamping device with displaced rotational axis

The main challenge of this concept is guarantee the synchrony of both systems, pulley and clamping device to ensure the synchrony between clamping device and projectile. The main options to produce the rotation to the clamping device and to ensure the correct synchrony with commercial parts are listed in the following:

- External power source electronically controlled
- Set of gears attached to the pulley axis
- Timing belt with pulleys attached to the pulley axis

To induce the rotation with an external power source electronically controlled to synchronize the clamping device with the pulley, a set of sensors and a new power source or a complex system to transmit the power from the main power source would be needed. This option is discarded because the addition of an external power source and a device electronically controlled is excluded in the requirements list. The second option above mentioned is to use the pulley as source to take advantage of its rotation. To transmit the power from the pulley to the clamping device, a set of gears or a time belt attached to the axis pulley are simple parts to fulfil the task. One problem is the little distance between both rotational axis (7,5 mm). To transmit the power directly, small gears are needed. Gears of the necessary size are likely to be damaged due to the high load to be transmitted. A set of bigger gears will resist the power transmission but a complex arrangement of gears and a structure to support the gears will be needed. The main problem is that the needed structure to support the set of gears will crash with the rotating clamping part due to the limited available space.

As the three above mentioned options for initiation of rotational movement do not comply with the requirements list, these options are discarded. Instead, a mechanical transmission is proposed. The transmission is composed by a rail attached to the pulley and a cylinder attached to the basic arm of the clamping device. To transmit the power, the cylinder is inserted inside the rail. The design is shown in Fig. 8.9.

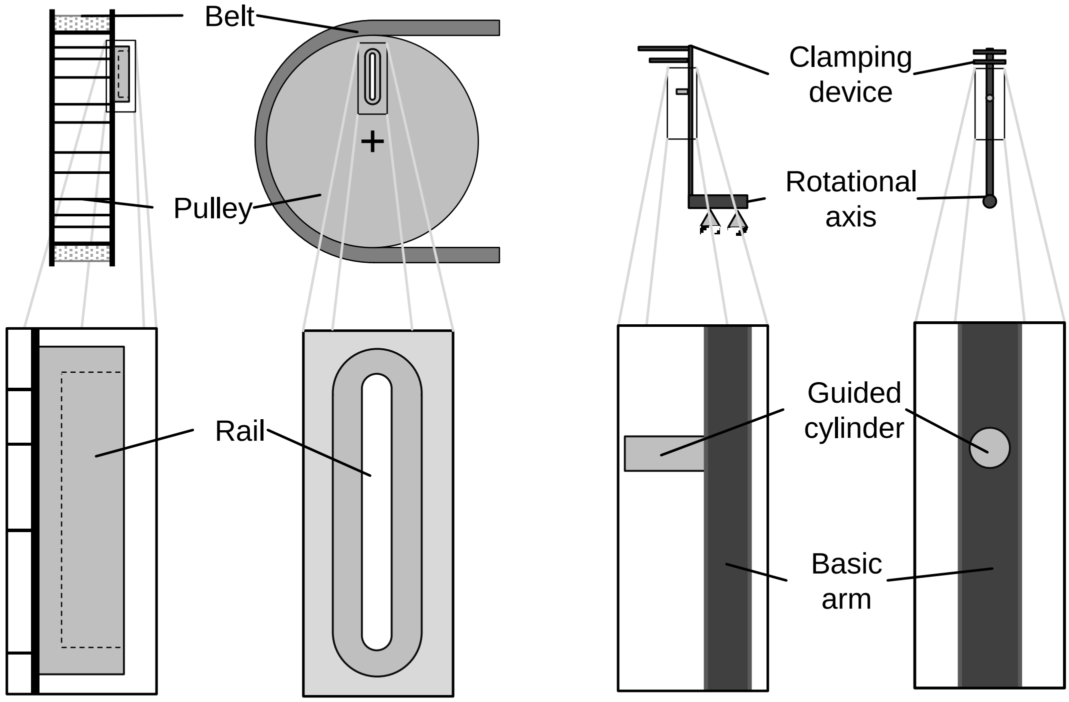


Fig. 8.9: Mechanical transmission between pulley and clamping device

The motion between parts and the forces during the whole trajectory is shown in Fig. 8.10. F_g its the force applied by the fixed rail to the cylinder. The relative velocity between cylinder and rail is defined as v_g. The line P_{pos} (Relative position of the projectile) is disposed to make clearer the motion steps.

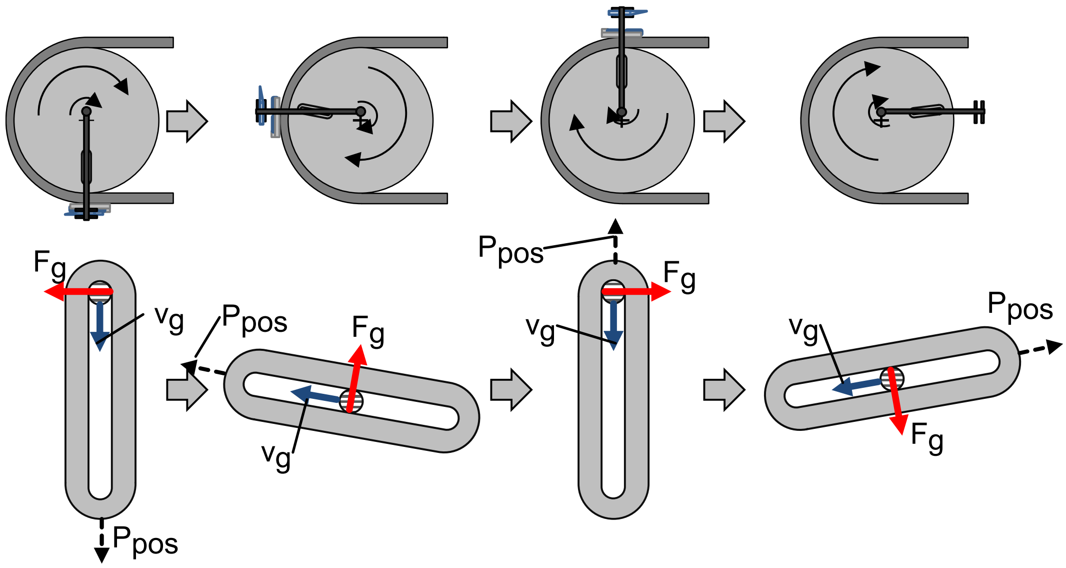


Fig. 8.10: Motion and forces between rail and cylinder

This transmission enables the clamping device to rotate at the same rpm without possibility to lost synchrony. Due to the fact that the circular trajectory of the clamping device has bigger diameter than the circular trajectory of the magnet holder and both are rotating at the same rpm, the linear velocity of the projectile will be bigger around the entire trajectory. The projectile will enter on the reed alienated in the “y” axis with the magnet holder but the velocity of the projectile will be 5,8% higher (77,35 m/s instead of 73,1 m/s [Gol15] at 1200 insertions/min).

With the concepts above explained, the functions hold and lift are fulfilled. To fulfil the requirements for realization of the functions “avoid collisions”, “attach the projectile” and “release the projectile”, the concepts explained in 8.1.2 will be evaluated in the next chapter. The concept selected after the evaluation will be combined with the Concept II.

9 Evaluation and selection

In the following chapter, the evaluation of the concepts explained in the previous chapter will be carried out. The purpose of this evaluation is the selection of the concept most suitable to fulfil the functions in reference to the requirements list. At the beginning, the evaluation of the variants of the concept B will be made. Next, the variant to rise the projectile of the concept I (A1 or A2) will be selected. Finally, an evaluation and final selection between concepts I and II will be carried out. The following concepts are going to be evaluated:

- Concept I, clamping device attached to the pulley.
- Concept A, modification to lift the projectile.
- Concept B, modification to attach and release the projectile.
- Concept II, clamping device with external rotational axis.

9.1 Separation between possible variants

Concept B (attach and release of the projectile) is combined with both concepts, Concept I and Concept II. Concept A (lift of the projectile) is only combinable with the Concept 1 as Concept II already has integrated the function of lifting the projectile. Fig. 9.1 shows the possible variants to be selected and combinations between concepts.

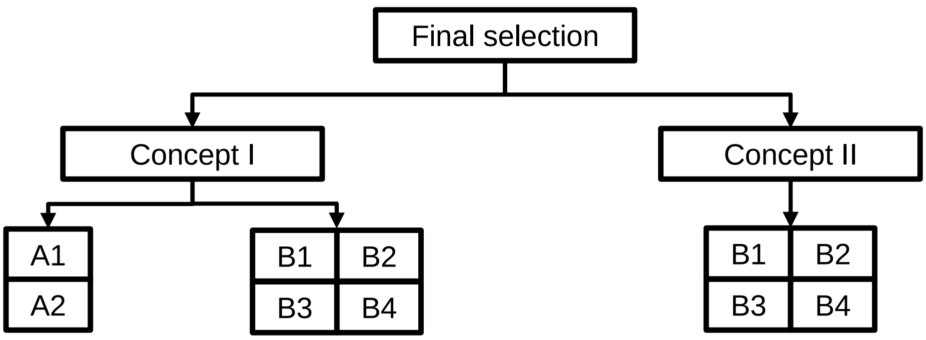


Fig. 9.1: Possible variants of combinations between concepts

To the identification of the combination between concepts, a spelling with the form Concept x,Ay,Bz will be used. The letters x,y,z are to identify the different variants (the letter x to define Concept I or Concept II, letter y to define Concept A1 or A2 and letter z to define Concept B1,B2,B3 or B4). Thus, in terms of Concept I, 8 possible variants can be selected (combinations between Concept A and concept B). The final variant of Concept I will be a combination between Concept A and Concept B (Concept I.Ay.Bz). Regarding concept II, 4 possible variants can be selected as a result of the variants of concept B.

Taking into account all these possible combinations, the final Concept will be selected between 12 variants, 8 variants of the Concept I and 4 variants of Concept II. To organize this selection, first an evaluation of the Concepts Bz is going to be made and the concept selected will be combined with Concept I and Concept II. Then, a selection between Concepts A1 and A2 will be made. Finally, the selected variant of Concept I (Concept I.Ay.Bz) and the selected variant of Concept II (Concept 1.Bz) will be compared and evaluated to select the final concept.

9.2 Evaluation of Concept A and Concept B

The evaluations will be visualized in form of tables. The symbols used to evaluate the concepts are shown in Tab. 9.1.

Tab. 9.1: Characters used to evaluate the concepts

Fulfilment of a criterion	Symbols used
Not fulfilled	--
Hardly fulfilled	-
Acceptable	0
Well fulfilled	+
Very well fulfilled	++

9.2.1 Evaluation and selection of Concept B

The function to be carried out by Concept B is the attachment and release of the projectile. The evaluation of the different variants proposed in 8.1.2 is shown in Tab. 9.2. The requirements listed in Tab. 9.2 are taken from the requirements list (Tab. 5.2). Furthermore specific requirements for the fulfilment of the specific functions of Concept B are listed.

According to the evaluation, Concept B3 and Concept B2 have the highest compliance with the requirements. The main advantage of concept B3 is the constant controlled movement by the geometrical restriction around the trajectory which shall ensure the movement of opening and closing smoothly in the precise phase of the trajectory. The main advantage of Concept B2 is the frictionless force to open and close the clamping part. The movement to open and close of the Concept B2 is less stable than the movement of the Concept B3 but due to the probable high friction of the Concept B3, the Concept B2 is recommended for a combination with Concept I and Concept II. Both concepts B2 and B1 are suggested to be tested in functional tests to verify the evaluation

Tab. 9.2: Evaluation of Concept B

Criterion	Concept B1	Concept B2	Concept B3	Concept B4
Small installation space	+	0	-	+
Compact design of moving parts to minimize inertial forces	-	-	++	--
Minimization of the added parts to the basic design	+	-	--	0
Safe fastening of the projectile	+	+	+	-
Avoid abrupt closing and opening	--	+	++	+
Minimization of frictional forces	-	++	--	0
Ensure complete opening and closing	+	0	++	-

9.2.2 Evaluation and selection of Concept A

The function to be carried out by Concept A is to lift the projectile to the reed´s height. The evaluation of the different variants proposed in 8.1.1 is shown in Tab. 9.3. The method to evaluate both concepts will be based in their advantages and disadvantages. This method of evaluation is used due to the high similitude between concepts.

Tab. 9.3: Evaluation of Concept A

Criterion	Concept A1	Concept A2
Advantages	Frictionless contact between mobile parts	Compact design of moving parts
	Small installation space	Exact position of the clamp during the complete cycle
Disadvantages	Intermediate position of projectile unstable	Frictional contact between static parts

The main advantage of Concept A1 is the frictionless movement to fulfil the function. The necessity of adding static parts and the frictional contact between the mobile parts and the static parts is the main disadvantage of the Concept A2. The exact position of the clamp during the complete cycle of Concept A2 is an important attribute but in this evaluation the frictionless movement of the Concept A1 is going to be more appreciated to minimize the power consumption. The Concept A1 is recommended for combine with the Concept I but suggested is to be tested in functional tests to verify the evaluation.

9.3 Final evaluation and selection

The final evaluation to select the concept to be proposed for implementation is shown in Tab. 9.4. The concepts evaluated are the Concept I.A1.B2 and the Concept II.B2. The method to evaluate both concepts is based in the Tab. 9.1 using as criteria of evaluation the requirements exposed in the requirements list (Tab. 5.2).

Tab. 9.4: Final evaluation

Criterion	Concept I.A1.B2	Concept II.B2
1. Geometry		
Small installation space	+	-
Compact design of moving parts to minimize inertial forces	--	++
Reduce modifications of the basic weaving machine to minimum	0	-
2. Kinematics		
Optimal trajectory passing of projectile on pulley	-	++
3. Forces		
Minimization of frictional forces	++	0
Minimum energy consumption	++	+
7. Maintenance		
Maintenance-free	0	0
11. Costs		
Minimum costs	+	+

According to the evaluation, Concept II.B2 has the highest compliance with the requirements. The detailed evaluation of both Concepts is given in the following:

- **Small installation space**: The external axis of Concept II.B2 with the necessary fixed point to rotate, requires more installation space than the Concept I.A1.B2 attached to the pulley.
- **Compact design of moving parts to minimize inertial forces**: The motion of the arm of Concept II.B2 only describes a circular trajectory with a fixed axis. Nevertheless, the motion of the arm of Concept I.A1.B2 is a superposition of linear and circular movement controlled by a spring which can oscillate. Hence Concept II.B2 fulfils the requirement of a compact design best.
- **Reduce modifications of the basic weaving machine to minimum**: Both concepts need to attach parts to the pulley but Concept II.B2 needs modifications to install the structure to fix its rotational axis. Hence Concept I.A1.B2 fulfils better the requirement of reducing modifications of the basic weaving machine.
- **Optimal trajectory passing of projectile on pulley**: The description of the advantages of Concept II.B2 in terms of trajectories of passing the pulley has been explained in subchapter 8.2. Concept II.B2 fulfils the requirement of optimal trajectory passing of projectile on pulley best.
- **Minimization of frictional forces**: Concept I.A1.B2 is attached to the pulley and all the mobile parts in contact are rotating at the same speed (frictionless contact). Nevertheless, the mechanical transmission to transmit the motion from the pulley to the external arm generates friction losses due to the motion between cylinder and rail (Fig. 8.10). Hence Concept I.A1.B2 fulfils better the requirement of minimization of frictional forces.
- **Minimum energy consumption**: Neither of both concepts needs an external power source to produce their motion. Nevertheless as above mentioned, Concept II.B2 has friction losses. These friction losses will produce an increment of the main engine consumption. Hence Concept I.A1.B2 fulfils better the requirement of minimum energy consumption.
- **Maintenance-free**: Both concepts are composed by elements suggested to be maintained (spring and mobile arm for Concept I.A1.B2 and bearings for Concept II.B2), therefore its compliance to the requirement is considered equal.
- **Minimum costs**: The components to build both concepts are simple commercial components and the difference in price is not appreciable. The cost to build the mechanical transmission of Concept II.B2 is considered equal compared with the cost to build the mobile arms with the spring inside of Concept I.A1.B2.

As the combination of Concept II and Concept B2 show the highest compliance with the requirements Concept II.B2 is recommended for further implementation in functional tests. Nevertheless, as Concept I.A1.B2 fulfils the requirements almost as well as Concept II.B2 the testing of both concepts is suggested to verify the evaluation.

10 Summary and outlook

The aim of this work is to develop a device for the safe positioning of a magnetic projectile in high speed magnetic weft insertion for weaving machines. With the development of this device, the loss of the projectile due to centrifugal forces in rotational areas of the moving path shall be avoided. Additionally the device shall be able to position the projectile correctly and smoothly for the initiation of next weft insertion at the target insertion speeds.

The development of the mechanical design was carried out in accordance with VDI 2221. After a clarification of the task, a list of requirements was made identifying the obligatory and desired requirements. Subsequently the investigation of necessary functions and their structure were established. This functional structure was used to develop principle solutions and basic concepts to fulfil respective sub-functions. By evaluating the fulfilment of requirements of the developed concepts, a selection of a combination of principal concepts was carried out.

The selected overall concept for the fulfilment of the main functions is composed by two principal modules. The first principal module is a clamp to hold the projectile, attaching and releasing the projectile at the necessary moment. The second principal module is a part to ensure the optimal trajectory of the projectile to lift it to the reed´s height with a superposition of linear and circular movement around the pulley.

The clamp holds the projectile by applying force to the functional surfaces of the projectile. Two linear guides are used to induce a linear movement of the clamp to attach the projectile at the bottom surface of the pulley and to hold the projectile during the passage of the pulley. With the linear movement of the clamp above explained, the clamp will open at the top surface of the pulley to release the projectile and to avoid collision with the timing belt. Allocating the static sets of magnets around the circular trajectory travelled by the clamp, the force to cause the linear motion is applied progressively. A magnet is also attached to the right surface of the clamp. To open the clamp, a part of the set of magnets is disposed to attract the magnet attached to the clamping part producing the force to open the clamp. To close the clamp, a part of the set of magnets disposed to repel the magnet attached to the clamping part producing the opposite force.

The second main module ensures the motion of the clamp to describe the correct trajectory around the pulley. The proposed module was a solid arm with an external rotational axis, displaced from the rotational axis of the pulley and supported by two attachment points (bearings). The main challenge of this concept was to guarantee the synchrony of both systems, pulley and clamping device to ensure the synchrony between clamp and projectile. A mechanical transmission was proposed. To maintain this synchrony, the transmission is composed by a rail attached to the pulley and a cylinder attached to the basic arm of the clamping device. To transmit the power, the cylinder is inserted inside the rail. This transmission enables the clamping device to rotate at the same rotational speed as the projectile without possibility to lose synchrony. The schematic structure of the suggested overall concept is shown in Fig. 10.1.

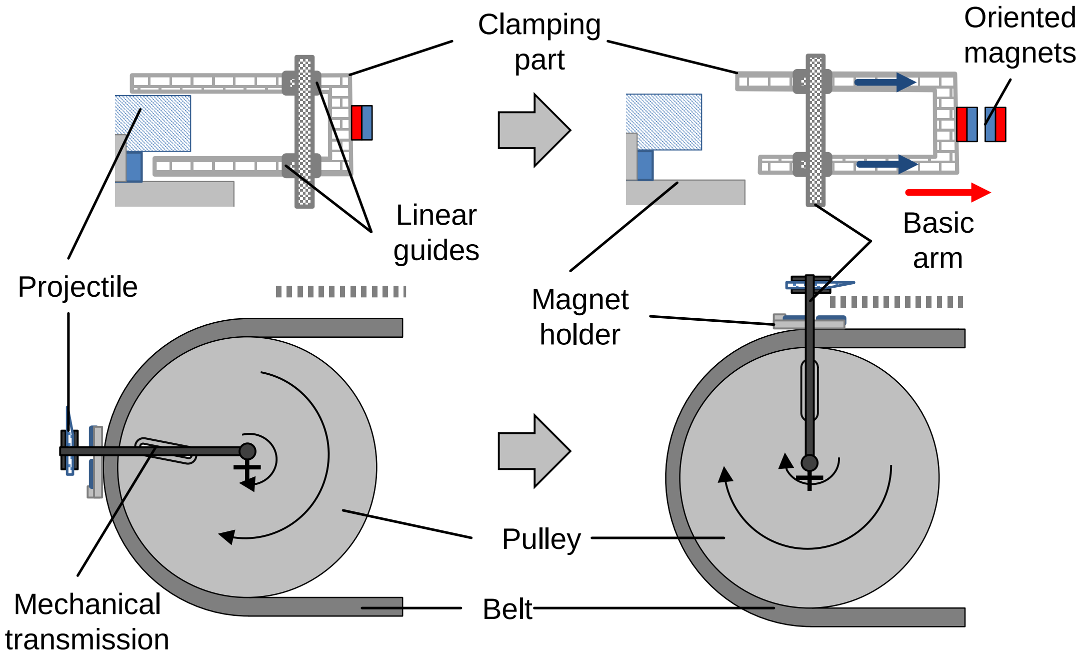


Fig. 10.1: Schematic structure of the suggested overall concept

These preliminary layouts are a basis for further creation of definitive layouts and the manufacturing of functional modules. After the manufacturing of the functional modules, functional tests are to be carried out. The main characteristics to be tested to ensure the correct working of the device are enumerated in order of priority as follows:

- Realistic scale of demonstrator to ensure transfer to real process
- Fulfilment of obligatory requirements
- Durability of the parts
- Consumption of power acceptable (friction between parts)

If satisfactory results are not achieved during the functional tests, other combinations of modules explained in this work can be implemented. If the results achieved during the test are satisfactory, the study to realize the implementation of the developed device into a real weaving machine follows.

11 Bibliography

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12 Statement of academic honesty

I hereby declare to the best of my knowledge that this thesis contains no material previously published or written by any other person. The work submitted in this thesis is the product of my own original research, except where I have duly acknowledged the work of others.

City, Date

Signature