TRANSFERRING OF MOVEMENT FOR STEERING EQUIPMENT

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PREFACE

This project has been made in co-operation with the Svedala Compaction Equipment AB Company. This project begun in December 2000 and was completed in May 2001.

We have followed the Fredy Olsson method and it has been a tool and guidance in the whole project. The report includes two phases: The Principle Phase and The Primary Construction.

We want to give many thanks to Svedala Compaction Equipment AB especially to our supervisors Lennart Olsson and Christer Nilsson for good advises and help.

We also want to give many thanks to the staff at the Department of Mechanical Engineering at the Blekinge Institute of Technology, especially to our tutor Mats Walter and Jan-Anders Månsson. We have also received good backup from our classmates when problems occurred with functions related to the CAD-programs or other, so we thank them also very much.

Karlskrona 2001
**SUMMARY**

This Examination Thesis was done at the Blekinge Institute of Technology of Karlskrona. The work is a part of the education to Bachelor of Science in product development.

The task consists of changing the steering wheel transmission of the CA soil compactor machine made by Svedala Compaction Equipment AB.

During the work we have followed the Fredy Olsson product development method. The work is divided in two parts: The Concept phase and The Primary Construction phase.

In the Concept phase we first defined the project. After that we did investigations to find different solutions, which were electronic solution, hydraulic solution, gears and shafts, belts, single wire and double wires. Then, we made descriptions of all the solutions, next step was a primary evaluation of the product solutions. We used three matrixes to find out which solutions we were going to keep for the progress of the project. And finally, we kept the belts.

In the Primary Construction we chose the belt using a criterions matrix. We designed the modifications of the different parts of the steering system with the I-DEAS CAD system. We also made some calculations and cost analyses.

The final solution is a new steering system, which is based on synchronous belts and pulleys. We think that the found solution is going to work successfully.

Karlskrona 2001

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Part 1

The Principal Phase
1. INTRODUCTION

1.1 The project

This project is an examination thesis and the development method of Prof. Fredy Olsson is important help to find solutions of the problems.[1][2]

The project started with a wish from the SVEDALA Compaction Equipment in Karlskrona to investigate problems about the steering wheel transmission on their vibrator rollers.

The present steering wheel transmission consists of roller chains, which are transmitting the turning movement from the steering wheel to the steering valve, which is a part of the hydraulic steering system. (See the Figure 3 and 4). The valve amplifies the drivers steering force and this powersteering makes it possible to control the machines which can have a weight of nearly 20 tons.

Unfortunately there is problems to keep the chains in tension and having a trouble free mechanism. So our studies consist of finding a better solution and change the chain-controlled system into a new reliable one.
Figure 2.

Figure 3. *Old system with chains*

1: Steering valve  
2: Sprocket  
3: Chains  
4: Steering shaft
**Figure 4. Old system with chains**

1: Steering valve  
2: Sprocket  
3: Chains  
4: Steering shaft  
5: Chain tensioner
1.2 Presentation of the group members

At the start there was only one member in the project group. In the middle of January two exchange students joined the group, which now consists of Imanol Sanz from Vitoria, Spain and Maxime Outhier from La Rochelle, France and Vilhelm Rydström from Åryd, Sweden. One of the two exchange students, Maxime Outhier, will leave in the middle of April for continued studies in France.

1.3 Presentation of the universities

1.3.1 Blekinge Institute of Technology

The Blekinge Institute of Technology is situated in the towns of Karlskrona, Ronneby and Karlshamn. These cities are located in Blekinge which is the name of the south-east part of Sweden. BIT is internationally competitive and the mission is to lead nationally in the profile areas: applied information technology and development of enterprises and society. The motto is quality and concern. This rather young academy was founded in 1989 and today there are about 3,500 students, 55% technology, 15% humanities, 15% social sciences and 15% health sciences.

As a small university, the strategy is to concentrate resources in targeted areas rather than try to imitate the breadth of the larger and older universities. The objective is to acquire and transmit knowledge and expertise in specific niches to meet national and international standards in these areas. By specialising, the students are provided with in-depth knowledge and understanding to the specialist areas.

The chief focus of the university is Information Technology; and the aim is to be the leading university in this field. The research has currently 30% of the budget and this is the highest percentage of any institution of this kind in Sweden.
Figure 5. Campus Gräsvik is located at the very beautiful shores of the Baltic sea and is the site of the Department of Mechanical Engineering.

At the Department of Mechanical Engineering there is activities like education and research about product development which is viewed with a comprehensive perspective regarding areas like environment, simulations, experiments and presentation with virtual reality. The education is made with close connection to and by assistance of powerful computers loaded with advanced software.

There are good co-operation with industry and other organisations in the region and all programmes include an extensive project, which is normally done together and in a collaborating manner with the industries representatives.

The atmosphere in the compartment is relaxed and informal for the benefit of open-minded students with a balanced view of their education.
The education programmes in the Mechanical Department are currently:

- Master of Science in Mechanical engineering with emphasis on Structural Dynamics.
- Bachelor of Science in Mechanical engineering with emphasis on Product development technique.
- Bachelor of Science in Mechanical engineering with emphasis on Virtual product development technique and design.
- Bachelor of Science in Mechanical engineering with emphasis on Computer science for Mechanical engineering.
- Technician: Applied manufacturing industry.
- Technician: Construction & Production technique.

The very important perspective of a sustainable development is a subject that is respected in all activities and product development tasks is always made with efforts to be in accordance with the four system conditions which are:

- No systematically increase with exploration of materials from the bedrock.
- No systematically increase with waste from materials used in industrial activities.
- No systematically destruction or enforcement of the nature caused by too big exploration of its recourses.
- No waste of the recourses, or injustice concerning the division of the recourses of the earth.
1.3.2  E.I.G.S.I : An French Engineering school

The university of Maxime Outhier

• The school:

The French engineering school is called EIGSI (Ecole d’Ingénieurs en Génie des Systèmes Industriels which means Industrial Systems Engineering School). There are about 500 students in the school.

*Figure 6. E.I.G.S.I*
• The environment:

The school is located in La Rochelle (500 km from Paris) on the Atlantic Coast. It belongs to a campus of 7000 students based close to the harbour of “Les Minimes” which is the biggest port of plaisance in Europe.

Figure 7. Location of La Rochelle

• The creation:

The school was founded in 1990 in La Rochelle. Former students from the French engineering school EEMI-VIOLET (This Electrical and Industrial Mechanic Engineering School is called VIOLET because of the name of the street it was placed in the beginning of the century) desired to created a new school which inherits of old tradition. Nevertheless they have built a school more adapted to the new industrial environment. Then, this new school called EIGSI received its first students in 1990.
• The education:

It is a five-year multidisciplinary school. Most of the students integrate the school just after the Baccalauréat, which is the equivalency of the A-level. Some students who have had curses can integrate the school in third year.

During the five years the students never specialise.

Many courses are followed such as:
- Mechanic
- Electricity
- Computer science
- Automatism
- Communication
- Thermodynamics

In order to valid the studies, the student have to make several training periods:

- In the second year, they have to make a training period as a worker in a company. The aim of this period of 7 weeks is to understand the life of company.
- During the fourth year the students work in-group of four in order to realise industrial studies for a local company. This study can be done in a European foreign country.
- In the fifth year the students make a training course in a company for 6 months. They work as an engineer. They also have a project to realise.

Thanks to the exchange programmes SOCRATES-ERASMUS, the students have the possibility to make these trainees abroad.
1.3.3  The University of the Basque Country

The university of Imanol Sanz.

The University of Basque Country/Euskar Herriko Unibertsitatea (UPV/EHU) is the public University of the Autonomous Community of the Basque Country. The UPV/EHU is an autonomous institution supported financially by the Basque Government. Founded in 1968 as the Universidad de Bilbao, the UPV/EHU was reorganised under its present name 1980, incorporating centres of higher education in the provinces of Alava and Guipuzcoa.

![Figure 8. Location of Vitoria](image)

*Figure 8. Location of Vitoria*
The UPV/EHU is a University that serves a bilingual society. The Basque language, Euskara, the only pre-Indo-European language still alive in Europe, has throughout its history, identified the Basque Country today. Although most courses are offered in Spanish, many Faculties and Colleges also offer courses in Euskara.

The UPV/EHU has three campuses:

Campus of Alava: Capital Vitoria-Gasteiz
Campus of Vizcaya: Capital Bilbao
Campus of Guipuzcoa: Capital Donostia-San Sebastian

In its thirty faculties and university schools, placed though the campus of Alava, Vizcaya and Guipuzcoa, we work, study and investigate more than 60,000 students, 3,500 lectures and a thousand professional staff.

Research is one of the cornerstones of the UPV/EHU. During the last few years its importance has been reflected in the huge increase in economic and human resources devoted to research.

Nowadays, the UPV/EHU is one of the first universities in Spain.

University School of Technical Industrial Engineering/Escuela Universitaria de Ingeniería Técnica Industrial (EUITI) of Vitoria-Gasteiz.

![Figure 9. The EUITI School](image)
The EUITI School

The EUITI is located in Vitoria-Gasteiz, the capital of Alava, and is in the campus of the same name.

The School was established in 1959. Today the School has about 1400 students, 100 teachers and 14 people as administration and services staff.

The EUITI collaborates with the Companies around the province as Ikerlan, Leia, Ayuntamiento de Vitoria-Gasteiz, SMC, IKT. Tuvisa, CTL, S.A., Fagor.

Seven diplomas are given by the Vitoria University School of Technical Industrial Engineering:

- Technical Industrial Engineering: Electricity
- Technical Industrial Engineering: Electronics
- Technical Industrial Engineering: Mechanics
- Technical Industrial Engineering: Chemistry
- Technical Engineering: Industrial Computers
- Technical Engineering: Topography
- Engineering: Industrial Management (Second cycle)
1.4 Presentation of the Company

Dynapac, now SVEDALA Compaction Equipment AB, started in 1934 with a share capital of 5000 SEK. The original name was AB Vibro-Betong and it was founded by Donovan Werner, Stig Giertz-Hedström and Ivar Strömberg.

Two years later (1936) the pendulum principle for concrete vibrators was patented. A mechanical engineer named Hilding Svenson who was working for the Company on a consultancy at high frequency but with a low-speed flexible drive shaft. It took him only two weeks to create the “pendulum poker” by taking an old mathematical principle already used by Leonardo da Vinci and applying it in a totally new way.

In 1940 the name of the Company changed to “AB Vibro-Verken”. In this next ten years Dynapac began to experiment with different prototype machines. In 1947 the first vibratory-plate compactor was introduced- a 1.5-tonne contraption that skipped along the ground and was jokingly called “the Frog”.

Dynapac’s first foreign subsidiary was founded in the USA in 1946. As a relatively small Swedish manufacturer of concrete vibrators the Company at first found great difficulty in being taken seriously. It was only when production of rollers started in the USA that business picked up. Today, Dynapac Mfg Inc, with its plant at Stanhope outside New York, is America’s leading manufacturer of rollers and many machines designed by the Company are also produced in other countries.

The research laboratory was inaugurated in 1948. After a long series of experiments the engineering department found the solution. The “ball-and-race principle”, patented in 1953, proved so successful that Dynapac towed rollers were soon in everyday use around the world.

After the USA, a small factory was set up in 1958 in São Paulo, Brazil, where 13 years later a much larger modern manufacturing plant was built. This has grown to be Dynapac’s biggest production plant with South and Central America as its principal market.

In Sweden the production resources were also increased. In 1960 the manufacture of heavy rollers was moved to a new plant in south-east Sweden at Karlskrona which is today the “technical centre” of the Dynapac Group.
In order to safeguard the Company’s continued expansion, which needed a lot of money, the founders decided in 1964 to sell it to Skånska Cement AB with whom they had co-operated closely since the beginning. Skånska Cement (renamed Industri AB Euroc in 1973) already owned several manufactures of building materials and was anxious to increase it’s international involvement.

In 1966 a Sales Company was formed in West Germany and 3 years later the number of employees passed 1000.

The final solution proved to be articulated steering—an idea borrowed from the wheel loader manufacturers.

Dynapac’s first roller based on this principle, the CA25, was introduced in 1970. It was an immediate success and is now the world’s most widely used heavy soil compaction roller. It has also become Dynapac’s most important product, even discounting the special-purpose versions and the smaller and larger models built according to the same concept that exist today.

In 1971 a Sales Company was formed in Canada and one year later (1972) in Norway.

In 1973 Company name changed to Dynapac Maskin AB and a Sales Company was formed in Australia; 2 years later one in France.

The number of employees was raising and in 1976 passed 2000.

In 1978 Dynapac acquired Salco, a small Swedish specialist company in road maintenance equipment, in order to be able to place on the market a basic range of such products without delay.

In 1979 Vibratechniques, a French manufacturer of concrete vibrators was acquired and in the same year a Sales Company was formed in Spain and Join-venture Companies established in Japan and Mexico.

Then in 1980 Dynapac completed its own first major development project in this field—a cold planer for asphalt and concrete roads.

The product range was further extended in 1980 through the acquisition of a small Canadian company, Pavemaster, and in 1981 by the acquisition of Japanese static roller manufacturer, Watanabe. In this same year a Sales Company was formed in United Kingdom.

In 1982 a Sales Company for light equipment was formed in USA.

With the additional acquisition in January 1984 of the West German asphalt paver manufacturer Hoes, Dynapac now has a comprehensive product range for road repair and maintenance—a field of rapidly growing importance, especially in the industrialised countries.
In 1991 Dynapac was purchased by the company of Svedala Industri AB with the head office situated in the town of Malmö.

Probably is Dynapac the world leading manufacturer of vibrating soil compactors today, with the company of Bomag from Germany as the most challenging competitor.

1.4.1 SVEDALA and the Environment

SVEDALA company is very conscious about the importance of the environment. Because of this, they have a particular policy to guide them. The responsible people of the environment matters do not only talk about it with the employees, they also do it with the customers, suppliers and general public.

Environmental policy

SVEDALA’s aim is to produce and sell products and services that contribute to the sustainable development of our environment. They achieve this by:
- viewing environmental efforts as an important operation within the Group.
- perceiving environmental work as an integral element in the management system.
- seeing laws and ordinances as minimum requirements.
- training and motivating their employees to act in an environmentally friendly manner.
- developing and producing their products and services with a view to the effective utilisation of energy, natural resources and recyclability.
- striving for continuous improvements.
- following up the Group’s environmental efforts centrally.
- maintaining an open dialogue with customers, suppliers, employees and the general public.
Organization and responsibilities

The company president bears the ultimate responsibility for the company’s environmental work. The environmental manager is responsible for ensuring that the Group’s environmental policy is adhered to and developed. Business area managers are responsible for ensuring that environmental consideration is shown in the development and use of the Group’s products, and that ecocycle principles are observed. The production managers are responsible for both the external and the internal environment in their respective production units, and for ensuring that environmental requirements are followed when products are packaged and shipped to customers. Country managers are responsible for environmental issues within their area of responsibility, with regard to service assignments, for example. All employees are responsible for creating a good work environment, minimising emissions and waste and informing their immediate superior in cases where their own competence and authority are insufficient.

GENERAL

In general, the environmental impact from their own production is limited. Where such an impact occurs, it mostly relates to extraction equipment at plants where casting, welding, vulcanisation and paint-spraying operations are carried out. As far as the work environment at their own production units is concerned, there is naturally strive for continuous improvements, and the same applies to their customers work improvements. Environmental consideration is always shown in the product development, not least in the recycling sector, where they now occupy a leading position in metals recovery, soil decontamination and the separation of various types of waste products.
2. DEFINITION OF THE PROJECT

Product definition according to the Fredy Olsson method
[1][2]
To receive an overarching picture and facilitate the construction of a product, viewpoints and descriptions according to this method developed by Fredy Olsson is used in areas like:

- **Product**
- **Process**
- **Environment and surroundings**
- **Human**
- **Economy**

2.1 **Product:** The steering equipment is transferring the turning movement from the steering wheel to the steering servo which is using hydraulic cylinders to turn vibrator rollers for desired driving direction.

2.2 **Process:** The present construction is using roller chains, which are running on sprockets to transfer the turning movement to the servo. Because of the insufficient reliability of this solution there are wishes for a more robust and reliable construction. The driver’s chair must be able to turn 90° in each direction.

2.3 **Environment and surroundings:** The rollers must be suited for work in varied and demanding environments with extreme effects from dust, dirt, moisture and other affects. Different vibrations are used to increase the cram of the ground and therefore the steering equipment must be resistant against this effect also. The suggestion of the new equipment should be suited for recycling and as much as possible harmless for the nature.
2.4 **Human:** Because of the safety for the driver and other persons the steering system must be extremely reliable and safe against breakdowns. The ergonomics and environment for the driver must not be impaired. The handling of the machine must also not be impaired.

2.5 **Economy:** The cost of the new steering equipment should not exceed the level of the present.
3. **RESEARCH OF THE PRODUCT:**

The research for solutions of the steering problem has been made with different methods like:

1. Internet investigations of databases like American Patent & Trademark office and European Patent office.
2. Visual examinations of machines with similar steering systems.
3. Discussions with technical skilful persons.
4. Internet search for interesting products, which are possibly solutions of the task.
5. Examination of catalogues and brochures.
6. Examination of books in libraries.

**Results:**

1. This research did not give any usable information.

2. Some of the examinations were done in service locations where helpful employees assisted in a very good manner. Other machines were inspected where they were used and the operator explained in some cases how the steering system functioned. This method gave some good ideas, mostly about electronic controlled systems, but since a mechanic solution is a must criterion the benefit wasn’t so good. Some ideas about hydraulic components were born though. Modern recreation and fast going plastic boats are equipped with interesting hydraulic steering but that alternative is too expensive according to one other must criterion which says that the price should not exceed the price of the present system.

3. With the help of the results from the visual investigations and advises from mentioned persons and other people like salesmen on steering manufacturing companies or representatives for foreign manufacturing companies and other consulted persons, interesting steering products could be found on the internet.
4. Internet gave information mostly about hydraulic or modern electronic-hydraulic equipment and their sales companies.

5. Contacted salespersons sent useful catalogues and brochures when those were requested.

6. The library investigation did not give so much useful information.

The effectiveness of a product investigation and the search for useful constructions or other desirable information is of course depending on the time and resources available. In this project a larger investigation could have brought more options according to the solving of this task. Unfortunately our must criterions like the economic limit and the wish for a mechanical system expels the most interesting and challenging alternatives from the modern technology.
4. CRITERION DISPOSITION:

D = Demand criterion
W = Wish criterion

4.1 Function

- The steering wheel must be able to turn easy. (D)
- The driver’s chair must be able to turn 90° in each direction. (D)
- The machine must be able to turn 30° in each direction. (D)
- The new system of transmission should be easy to install. (W)
- The new system must be a mechanical one. (D)
- The system must not have play or transfer inaccurate motion. (D)

4.2 Operation criterion

- The system must be able to function in demanding environment with dust, sand, water and dirt. (D)
- The system must be able to take different vibrations. (D)
- The system must be very long lasting and not dependent of service, so a good reliability. (W)

4.3 Personal safety

- The system must be safe for the driver and other persons. (D)
- The system must fulfil the rules of CE-marking. (D)
4.4 Ergonomics
- The system must not impair the comfort for the driver. (D)

4.5 Technical service
- The system must be designed for quickly and easy service and replacement. (D)
- The system must be easy to check for service conditions. (D)

4.6 Environment
4.6.1 Manufacturing
- The system material must not be harmful for the environment. (D)
- The system should be as effective as possible concerning the material used. (W)

4.6.2 Operation
- The system must not be harmful for the nature during operation. (D)
- The service products, used by the machine, must not be harmful for the nature. (D)

4.6.3 Elimination
- The system must not add dangerous material for the nature. (D)
- The different parts used should be marked for easy recycling. (W)
4.7 Economy

4.7.1 Manufacturing

- The system should be as costeffective as possible. (W)

- The system should not be more expensive that the present. (W)

- The system must not cost more than the double of the price of the present one. (D)

4.7.2 Usage

- The system should be as cheap as possible to use. (W)

4.7.3 Elimination

- The system should be as cheap as possible to recycle. (W)

- If the totality of the system can not be recycled, it should be as cheap as possible to destroy. (W)
5 DESCRIPTION OF THE SOLUTIONS:

5.1 Electronic solution:

This outstanding technical advanced solution gives many opportunities to control the machine. The driving direction control and other functions can be set by a joystick or a mini steering wheel, which gives benefits like improved ergonomic and comfort for the driver. It is even possible to control the machine by remote control with a moveable unit. There will also be possibilities for distance control and surveillance by the use of satellite navigation; computer controlled schedules, sensors, cameras and monitors. Then the roller could be operated without driver. These methods could be used when great areas are compacted and also when it is dangerous for a driver to operate the roller. These unique possibilities give opportunities to develop a most flexible tool for ambitious designers. Other advantages with the use of electric equipment are the simple installation and the reduced number of hydraulic hoses and couplings that can cause hydraulic oil leakage in the nature. There will also be fewer components that need adjustment and service. It is also possible to install a simple emergency control system by the use of wires so the machine will be possible to operate even if the electronically system would fail by different reasons. Of course will this extra security and options add some cost but the customers will have a very reliable and ultra modern tool if they have need for, and want to pay for these functions.

An electronic driving control can function by direct influence from the mentioned control options, which with the help from an electronic steering unit controls a hydraulic valve unit. The valve unit can with advantage be placed nearby the hydraulic steering cylinders and the whole hydraulic function regarding the rollers steering control can be made with a very compact design. Probably would this solution be excellent concerning the important vibration aspect, if the components are chosen carefully and mounted in a way that isolates them as much as possible from the rollers powerful vibration work.
Regarding the B solution with the removable steering wheel, there must of course be some kind of mechanical function also. Concerning the status of the two electronic solutions in the matrixes, we consider them equal in this matter.

Figure 10. Electronic solution A

1: Joystick
2: Electronic hydraulic valve control
3: Hydraulic steering cylinder
Figure 11. Electronic solution B

1: Holder for removable steering wheel
5.2 Hydraulic solution:

This solution could be ranked as the second best solution. But the economic must criterion eliminates it. There are wishes from the factory to not use the existing pressure in the present hydraulic system, so we have limited the product research to systems that works without it. The system consists of an oil circuit, where the oil pressure comes from a pump mounted on the steering wheel. The movement of the wheel activates the pump, which creates the oil pressure that moves the piston in a hydraulic cylinder. This linear movement is translated to a circular movement by a zip-gear wheel or a hydraulic motor mounted on the steering valve. To permit the platform to rotate 180° a swivel connection is placed between the turn able driver’s seat and platform or the cabin frame. Unfortunately there is environmental aspects regarding the hydraulic oil since the type of hydraulic pumps that has been found needs aircraft oil quality, and this liquid is not so friendly to the nature. Perhaps it would be possible to find a pump that works with vegetable oil quality or some other more suitable hydraulic oil, seen from the ecological aspect.

Concerning the B alternative we are using a hydraulic motor to transfer the turning movement to the servo component and expel the swivel connection. The swivel connection can of course be expelled in the A solution also and then get a cheaper construction. But if a long time solution is wanted then the swivel connection is preferable even if friction protections are used on the hoses.

Concerning the status of the two hydraulic solutions in the matrixes we consider them equal in this matter.
Figure 12. Hydraulic solution A

1: Manually engaged hydraulic steering pump
2: Hydraulic hoses
3: Swivel connection
4: Zip gears
5: Hydraulic cylinder

Figure 13. Principle of zip gear
Figure 14. Principle of hydraulic solution

Figure 15. Hydraulic solution B

1: Manually engaged hydraulic steering pump
2: Hydraulic hoses
3: Hydraulic motor
5.3 Gears and Shafts:

We need three gear units with 90° angle between the gear shafts to transmit the movement of the steering wheel to the steering valve and three shafts to connect these gear units.

In this solution, the position of the steering valve is changed from a vertical to a horizontal position, to save the cost of one gear unit. This variant should be very stable and reliable. The gearboxes have some play between the gears and this play follows the price, so if an almost play free system should be achieved the cost, the cost will be considerably. The component service is very likely reduced compared to the existing system. There are units available that are lifetime lubricated and this is an important advantage concerning the service aspects. Some minor construction changes regarding the turn able platform probably have to be done, so there will be more space for these enclosed and protected gear units.

![Figure 16. Gears and shafts solutions](Image)

1: 90° gear unit
2: Connection shaft
3: Steering valve
Figure 17. Gear unit
5.4 Synchronous belts:

It is principally the same system as the present one but the transmission is consisting of belts instead of by chains. There are many variants of these belts and they are normally reinforced with steel wires or other similar material. The progress regarding the belts strength and durability has been considerably improved in recent time and they are even used with advantage instead of roller chains to transmit the great engine power to the rear wheel on motorcycles like Harley Davidson. When a company like HD chooses a construction solution since many years, one can be sure that the function and reliability has been tested out carefully. The durability is greatly improved if the belts are protected from contamination by a suitable cover in the rear and lower section. The installation is also easy performed because the working principle is identical to the roller chains. The stability in the vertical direction is also improved since the belts haven’t got any links like the roller chains that can permit movement in this direction. The pulleys can be equipped with steering edges to keep the belts on the tracks and prevent the belts to slip off the cogs. As far as we can estimate the belt is superior compared to the roller chain in most aspects except perhaps the recycling possibilities.
Figure 18. Belt solution

1: Pulley
2: Synchronous belt

Figure 19. Principle of synchronous belt
5.5 Single Wire:

In this solution, a unit, which is activated by the movement of the steering wheel, moves a push and pull, wire. The wire stirs the zip-gear wheel, which transmit the movement to the steering valve, like the hydraulic solution, or a similar unit as on the steering wheel shafts is used on the steering valve also. (See figure 23) The function of this single wire movement is probably not so accurate since there can be some slack in the mechanism. There is also a demand on rather great bending radius to assure acceptable friction between the wire and the casing. Unfortunately there is not so much space for those bends since the turning mechanism of the platform calls for a placement of the wire through the centre of the circular turning movement. The wire can be mounted through a slot as on the pictures to avoid bends with too small radius on the wire. This solution is used for a long time on recreation and sports boats so it works satisfactory for this need, but the durability for the wire solutions are not comparatively to the other solutions, not even the gears or the belts. The prices of the wire solutions are very competitive though, but probably will the service aspects and the lack of long time durability cause problems. The durability of the wire casing is improved a lot if there are friction protections on the outside where the casing has contact with other parts. One problem about the zip gear with this solution, is that the length of the wire that is not supported by the casing can not be to long, because of the risk of bending the wire. Because of this problem the steering valve probably have to be changed to a model that do not need six turns for proper steering of the roller.

Concerning the status of the two solutions in the matrixes we consider them equal in this matter.
Figure 20. Single wire solution A

1: Wire transferring unit
2: Push and pull wire
3: Pipe for loose end of wire
4: Zip gear

Figure 21. Principle of single wire

Figure 22. Principle of zip gear
Figure 23. Single wire solution B

1: Wire transferring unit
2: Push and pull wire
3: Pipe for loose end of wire
5.6 *Double Wires:*

Here, the steering wheel rotates a disc where one or two pulling wires are connected. The wires follow suitable tracks that are made on the surface of the disc. A cover should protect the whole arrangement, to keep the wires and other parts protected from pollution. This cover could also function as a track keeper for the wires, so the wires can not come out from the tracks even if they are slackened. Of course, some kind of tightening mechanism has to be used to gain a play proof function.

A similar disc rotates the steering valve in the other end of the system. This variant is considered more accurate regarding slack or play in the steering motion, compared to the single wire solution. But like the single wire, also this variant is considered to not be very wear resistant for long time, trouble and service free use. It is also a need for protection of the casing surface like the single wire alternative. These wires and casings accept smaller bending radius compared to the single wire, because they are thinner and more flexible.

Concerning the status of the two different solutions in the matrixes we consider them equal in this matter.
Figure 24. Double wire solution A

1: Cable pulley for movement transferring from the steering wheel
2: Cable or wire
3: Cable casing

Figure 25.
**Figure 26. Double wire solution B**

1: Cable pulley for transferring of the steering wheel movement  
2: Cable or wire  
3: Cable pulleys

**Figure 27.**
6. PRIMARY EVALUATION OF PRODUCT SOLUTIONS:

According to the Fredy Olsson method of product development, evaluation matrixes are used for more safe and effective solution selections. [1][2]

“Wish criterions” for the evaluation matrix used for measuring the importance of the wishes.

A = The new system of transmission should be easy to install.
B = The system should be as effective as possible concerning the material used.
C = The different parts used should be marked for easy recycling.
D = The system should be as cost effective as possible, but with good quality. (Manufacturing)
E = The system should not be more expensive that the present.
F = The system should be as cheap as possible to use, but with good quality
G = The system should be as cost effective as possible to recycle.
H = If the totality of the system can not be recycled it should be as cheap as possible to destroy without any harm for the nature.

Instructions:

- Compare A/B, if A is more important than B, it is 2 points. If A is equal to B, it is 1 point. If B is more important than A, it is 0 point.
- Compare A/C, A/D, etc.
- Compare B/C, B/D, etc.
Matrix for the “wish criterions”:

<table>
<thead>
<tr>
<th>Wishes</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<th>F</th>
<th>G</th>
<th>H</th>
<th>CF</th>
<th>Pi</th>
<th>Ki</th>
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</tbody>
</table>

**CF** = Correction Factor  
**Pi** = Total points  
**Ki** = Importance Factor
“Demand criterions”: for the evaluation matrix used for measuring the importance of the wishes.

A = The steering wheel must be able to turn easy.
B = The driver’s chair must be able to turn 90° in each direction.
C = The machine must be able to turn 30° in each direction.
D = The system must be able to function in demanding environment with dust, sand, water and dirt.
E = The system must be able to take different vibrations.
F = The system must be very long lasting and not dependent of service, so a good reliability.
G = The system must be safety for driver and other operating staff.
H = The system must not impair the comfort for the driver.
I = The system must be designed for quickly and easy service and replacement.
J = The system must be easy to check for service conditions.
K = The system material must not be harmful for the environment.
(Manufacturing)
L = The system must not be harmful for the nature during operation.
M = The service product, used by the machine, must not be harmful for the nature.
N = The system must not add dangerous material for the nature.
O = The new system must be a mechanical one.
P = The system must not cost more than the double of the price of the present one.
Q = The system must not have play or transfer inaccurate motion.
Matrix for the “demand criterions”:

<table>
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<tr>
<th>Demands</th>
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<th>C</th>
<th>D</th>
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<th>M</th>
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<td>3</td>
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<td>3</td>
<td>43</td>
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</tr>
</tbody>
</table>

3 = For sure  
2 = Maybe  
1 = Probably not  
0 = Not possible

We will not develop the “electronic solution” because the factory doesn’t have wishes for further development of it at this time. The “hydraulic solution” is not interesting either because this construction will cost more than the double of the price of the present one. The most interesting and realistic solutions are the belts and the gears, so these suggestions are transferred to the next judgement matrix.
Criterions for the evaluation matrix of the “wishes”:

A = The new system of transmission should be easy to install.
B = The system should be as effective as possible concerning the material used.
C = The different parts used should be marked for easy recycling.
D = The system should be as cost effective as possible, but with good quality. (Manufacturing)
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G = The system should be as cheap as possible to recycle.
H = If the totality of the system can not be recycled it should be as cheap as possible to destroy, without any harm for the nature.

Evaluation matrix of the “wish criterions”:

<table>
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<tr>
<th>Wishes</th>
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<th>C</th>
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<td>20/64</td>
<td>10/64</td>
<td>2.21</td>
<td>0.74</td>
</tr>
</tbody>
</table>

U = Score for the should criterions
T = Importance of the should criterion

3 = For sure
2 = Maybe
1 = Probably not
0 = Not possible

This last matrix picks out the “gear solution” as the most advantageous solution, regarding the stated criterions in this matrix, but the
“must criterions” matrix shows that the “belt solution” is the best alternative to develop, and since the must criterions are more important we have a winner.

Presentation of the chosen solution.

According to the results from the stated criterions and matrixes the solution “Synchronous belts” will be developed further.

The belt solution was chosen by reasons like:

• Very easy to install.
• Very easy to perform service.
• Good resistance against vibrations.
• Small changes on the turn able platform.
• A very cost-effective solution.
• Good durability.
• A very precise construction concerning play or backlash.

There is almost only advantages with this solution. Because that the function is similar to the existing chain solution, probably there is not any need for large modification of the turn able platform. Other parts, which probably can be kept in the same way with small modifications, are the shafts with their bearing mechanism. The vibrations will very likely not cause any problem with the belts and the wheels. In general the construction task is limited to modifications and refinements. But there are questions to investigate about the resistance against heat up to 80°C, oils like hydraulic oil, diesel oil and engine lubricating oil, grease, and ageing-aspects. Presumable there are qualities, which can stand these influences, but since the belts should be protected from contact with hydraulic oil or other destroying substances by sealing covers this will probably not be a problem. One other big problem, which has to be investigated, is that if the material of the belts body, called polyurethane (PUR) is hazardous to the nature. This is very important in all phases of the lifetime which are, manufacturing, using, recycling and/or elimination. The Primary construction phase will hopefully give us the answers.
Part 2

The Primary Construction
7. INTRODUCTION

The Primary phase is a continuation of the Concept phase where the chosen concept solution or solutions is developed to a useful product. Ready-made products are convenient and efficient to use and they are often more cost-effective than self-developed items. If the manufactured number of units of the used product is very high it can be a good idea to develop a “tailor made” product though. We will use the word “component” for this ready-made product. If it is difficult to find a suitable component or if it is very expensive it can often be necessary to manufacture a special part and we will call this item “detail”. These components and details can with advantage also be divided into routine processed or special processed parts. The routine processed parts are usually components or simple details that there are no needs for further investigations or explanations. The special processed parts are more interesting for examinations like calculations, explanations and other necessary more extensive work. To get an overlooking and efficient method to find solutions for the need of components or details, one can use criteria’s and matrixes to evaluate the found suggestions. Details can often be made in many ways, so if there are not any obvious solution it can be a very good idea to develop several constructions for the mentioned method. According to the Fredy Olsson product development method, one often uses criteria’s like:

- Product
- Process
- Environment and surroundings
- Human
- Economy

A product compile shows how the product is finally built and also gives direction to the assembly drawings and parts drawings. The last steps in the product development are the construction and assembly of prototypes, and tests of these to find out if the ideas are working with satisfaction. If not, adjustments will be necessary to reach the goal in the best case. In this project, we aimed for a prototype construction, but unfortunately unexpected difficulties, which we will explain about later in the work, resulted in too much lack of time.
Figure 29. Assembly 2
Figure 30. Assembly 3
8. TABLE OF THE DIFFERENT COMPONENTS/DETAILS AND THE TYPE OF PROCESS

In the following table we will describe the components and details of the steering system and the structure parts we have constructed or modified. Because that this project is more a matter of modifications rather than a new construction we have only notified the parts that are new or modified. We have also indicated the position on the product compile or the assembly drawings so it is easy to find the part for further examination. We have constructed a version for the platform model of the Dynapac CA-rollers. With some minor modifications mostly about the middle shaft, it will suit the cab model also.

<table>
<thead>
<tr>
<th>Component / detail</th>
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<th>Unique</th>
<th>Assembly/position nr:</th>
</tr>
</thead>
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<td>Special-process</td>
<td></td>
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</tr>
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<td>Ass.3 Pos.27</td>
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<td>Pos.19</td>
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<td>Ass.2</td>
<td>Pos.21</td>
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<td>Ass.1 Pos.3</td>
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</tr>
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<td>X</td>
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<td>Ass.2 Pos.11</td>
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</tr>
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<td>Ass.1 Pos.7</td>
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<td>X</td>
<td>Ass2 Pos.12</td>
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<td>X</td>
<td>Ass.2 Pos.12</td>
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<td>Special-process</td>
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<tr>
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<td></td>
<td></td>
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<tr>
<td>Belt pulley, upper rear, diam. 95.17x30</td>
<td>1</td>
<td>X</td>
<td>Ass.3</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Belt pulley, lower front, diam. 97.71x30</td>
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<td>X</td>
<td>Ass.3</td>
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<td>X</td>
<td>Ass.3</td>
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<td>Stop screw M6x12, flat end</td>
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<td>Belt tensioner, Mulco B 40/80-0 B/E0</td>
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<td>Screw hex head, M12x45. zincified</td>
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<td>Washer, 13x24x2.5. zincified</td>
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<td></td>
<td>Pos.43</td>
<td></td>
</tr>
<tr>
<td>Washer lower front pulley. (new part)</td>
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<td>X</td>
<td>Ass.3</td>
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<tr>
<td>Belt Guard: 372672. (modified)</td>
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<td>Pos.46</td>
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</table>
9 PRODUCT STRUCTURES

We described the current steering system and the chosen replacement we have developed rather briefly in the concept phase. To get a good understanding of the coming information the new construction has to be explained more thorough.

The driver of the roller controls the machine from a turn able module which can be rotated 90° in each direction to with this have full attention in both driving directions. Two synchronous belts transfer the rotating movement of the steering wheel, which affects a steering valve that is a part of the hydraulic system. Without this aid it would be impossible to control the machines that can have a weight up to nearly twenty tons.

The belt system requires rather tight tolerances according to the parallelity of the pulley shafts and therefore it is in some cases necessary to adjust the structure and parts so the system can fulfil these demands. [13]

The laser cut steel plates of the structure can be welded together very precise if steering knobs are formed on the edges of one of the plates, and these knobs fits very precisely in holes which are cut in the other plate. For that reason the plates gets a very good parallelity and hence the shafts will follow if they are mounted in a proper way.

The shafts will be located in fixed positions except the lower rear shaft, that will be movable forward and backward to supply tension to this belt. The fixed positions simplifies the mounting and reduces the risk for mistakes when performing service on the steering equipment especially if the person that carry out the work is not experienced in mechanical service work, like in primitive parts of the world. If the construction is made in a way that mistakes can happen they will probably happen some time and this is not acceptable when it can affect a safety sensitive system like a steering system.

A double crosspin cardan joint is placed between the steering column and the front linkage shaft for smooth handling and to compensate for possible alignment failure of the structure plates.
10. CHOICE OF COMPONENTS

This product development work is as mentioned before a matter of refinement of an existing steering system rather than a new concept. If it is possible to solve a problem with well-tried and reliable methods there is in our opinion not any need to investigate a lot of components that will not make the job in a better way. Is it obvious that the component do not have a serious competitor we feel that it is a waste of time to find out a lot of information about a part that will not be used for sure. But if there is alternatives that can be better the Fredy Olsson method with criterions and matrixes is superb.

10.1 Poor drawing information

Unfortunately we had very poor information about steering shafts made by a supplier in Italy. The drawings we had, showed only the outer dimensions of the pipes, which the plate holders are welded to, and the shaft ends. Therefore we did not know important facts about parts which are inside this shaft holder pipe. The shafts are made in cost-effective way with both solid parts and pipe parts welded together. Since we realised that this was a simple and good method to use, we did not want to change this principal construction. We tried to get the necessary information about the dimensions and material of the front steering shafts and the steering valve shaft from the manufacturer in Italy, but there were exhibitions and other trade fairs going on in this time and the constructors were not available for supplying this information. Therefore we did not succeed to get this basic information in time to be able to perform calculations and other necessary dimensioning work of these shafts. We only have a limited time to make this examination thesis and we could not wait for the information, so we had to go on with the work to finish it in time.

But we have full information about the middle shaft from the Svedala Compaction drawings, and when we compared the strength of the shaft with the safety demand from the factory we found out that this shaft will not even handle the moment with a security factor of 1.0, which means 108 Nm and we were supposed to apply a moment with a security factor of 1.5 which means 162 Nm. These calculations will be supplied later in the work where we explain about the shaft constructions.
We informed our contacts at Svedala Compaction about that the whole system with the shafts has to be upgraded to a stronger dimension and got the answer that there has not been any problem with the shafts or other equipment related to them so we could leave this dimensioning work to be calculated at another time, preferably when the prototype would be constructed and put together for long time testing. Therefore the necessary calculations for a safe and reliable steering system like static calculations, fatigue calculations, natural frequency investigations and calculations are missing in this project which can be experienced as strange, but we want to inform the reader why they are not present.

We will now try to explain how we picked the ready-made components.

10.2 Demands on the components

Product
The steering system components must be:
• easy to install and remove in the construction.
• easy to perform service on.
• durable and have a long lifetime.

Process
The steering system components must be:
• suitable to handle the safety demands from the factory.
• be smooth and precise.
• without play in any function.
• designed for a minimum of service necessity.
Environment and surroundings
The steering system components must be:
• harmless for the nature.
• suitable to handle the rollers oils and chemicals.
• suitable to handle a temperature of +80°C.
• resistant to the rollers great vibrations.

Human
The steering system components must be:
• safe for the driver and other persons.
• comfortable and easy to handle.

Economy
The steering system components must be:
• costeffective and not be considerably more expensive than the present.
• costeffective regarding spare parts and service.
• made of long lasting components.
10.3 The synchronous belt

When we decided to use synchronous belts for the steering, we found out very soon that it is not an easy task to pick out the best alternative. So this is absolutely a subject for a thoroughly investigation. Svedala Compaction Equipment has worked out a safety demand on the steering parts, which also have to be fulfilled by the belts. The reasons for these demands are that if a very fast movement of the steering wheel is performed, like in a panic situation, the steering valve does not respond in the same speed. The consequence can be that the driver tries to control the steering with pure muscle strength, which is as mentioned before a very tough task with a machine that has a weight of nearly twenty tons. Another reason can be that if the drum in the front hits a stone or a edge of something hard, a force is transmitted to the steering system, and this stress can influence the system in a very bad manner.

Figure 31. A synchronous belt with pulley
10.4 Calculation of the moment and forces

The criteria of the demand is that a force of 600 Newton should be possible to apply on the steering wheel, which have a diameter of 360 mm. And then as an additional security factor, we had instructions from Svedala Compaction Equipment. to multiply this result with 1.5.

![Diagram of steering wheel with force and diameter](image)

Figure 32.

So the moment that the belt equipment and other parts have to take will be:

\[
M = F \times \left(\frac{D}{2}\right) \times 1.5 = 600 \times 0.18 \times 1.5 = 162 \text{ Nm}
\]

Since the smallest pitch diameter is 96.77 mm, that we use, because of space limits for the belt pulleys, which is the ones placed in the upper position the force in the belt will be:

\[
M = F \times r \quad \Rightarrow \quad F = \frac{162}{0.0484} = 3348 \text{ N}
\]

The belt that we are going to use must of course be able to handle this force for a long time without any doubt. It is also important to select a belt that is not too wide because the wider the belt is the higher are the demands on the parallelity of the shafts and belt pulleys. If this demands from the manufacturer of the belts is not satisfied there are possibilities that the lifetime of the belts is considerable reduced.
10.5 Selection of the best belt for our needs.

To succeed in our search for the strongest and best belt for this task we made a quite comprehensive research about the belts on the market and stipulated relevant criteria’s for comparison of the candidates, which can be seen below. [11][13][15][16]

10.5.1 Criterions for the belts

A) The belt must be able to resist a maximum force of 3500 N.
B) The width of the belt must be as small as possible to avoid great reconstruction of the platform and also for avoiding extremely small tolerances for the construction.
C) The belt must be resistant to the different kinds of oil and chemicals, which the machine works with.
D) The belt must be able to operate in high and low temperature.
E) The belt must be as cost effective as possible.
F) The belt must not be harmful to the nature.

<table>
<thead>
<tr>
<th>Belt manufacture</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Sum</th>
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<tr>
<td>HABASIT AT 10</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<td>17</td>
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<tr>
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<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
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<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 10.

As we can see there are not any doubts about which belt that is most suitable for our needs and we will continue the developing of the steering concept with this alternative. According to the C criteria we have performed a test of the belts which are involved in the selection to see how they can resist oils and other chemicals actual on the rollers and the results are not disadvantageous for the chosen belt. We will show how we did it in the following part.
10.6 Oil resistance test

To find out if the belts can resist the existing chemicals and oils that exists on the rollers we were supplied with these by Svedala Compaction Equipment in cans. The actual belts, which were supplied by the manufacturers sales agents, was cut in pieces and inserted into the cans. The oils and chemicals were:

- Shell Rimula engine lubricating oil
- Shell Naturelle hydraulic oil
- Shell Tellus hydraulic oil
- City diesel oil
- Lubricating grease
- GlycoShell glycol

The belt pieces showed no sign of influence from the chemicals after nearly two months, except that the Habasit AT 10 changed colour from white to slightly yellow in the:

- Grease
- Shell Tellus
- City diesel
- GlycoShell

The other belts, which are in other colours, did not even change colour what we could see anyway. We will give back the cans to the company with the belt pieces still inside, and the time will tell if the different polyurethane materials can resist a long time influence. A more thorough test with simulations and other methods would of course be more decisive but the time did not allow it. We think it is better to make a test like this than nothing at all to investigate the possibility of sensitivity to the mentioned chemicals. The belts should be protected from this influence by covers so the danger of damage of the chemicals is not so likely in the reality.
10.7 The Gates Poly Chain GT2 synchronous belt

This belt is probably the strongest synchronous belt in the world and it is special designed for high torque and low speed drives. The body and teeth are made of polyurethane compound, which makes it tough and highly resistant to abrasion and virtually immune to chemical attack. Aramid tensile cords are the belts muscles and they exhibits exceptional flex fatigue life and absorbs shocks and surge loading. The belt is exceptionally durable and remains fully operational from -54°C up to 85°C. When properly designed and applied poly chain GT2 belt drives will be as much as 98% efficient thanks to the non-slip characteristics of synchronous belts. Chain drives running unlubricated generate significant heat build up due to increased friction in the roller joints. Even lubricated chain drives are typically only 92-98% efficient.[13]

The belts we use are called: Upper: PolyChain GT2/8MGT-1120-21
Lower: PolyChain GT2/8MGT-1000-21

Figure 33.
10.7.1 Strength of our belt alternative

Our choice of belt which is 21 mm wide and has the identity name of 8MGT. The 8M is the characteristic of the profile of the teeth or cogs, there is another bigger size called 14M also, which is suited to handle greater power. The power, which the belts shall handle, is a little different depending on if it is the upper or lower belt because the centre distance and the belt pulley diameters are different. The moment, which we apply, is the safety demand of 162 Nm.

The upper belt shall be able to handle a power of 3349N and the maximum allowed force applied for a long time load is 3575N according to information that was supplied from the manufacturer, Gates. The lower belt shall be able to handle a power of 3263N and the maximum allowed force applied for a long time load is 3720N. The limit force for breakage is 14485 N on both belts, of course.

Figure 34. Gates Industrial belts

Figure 35. A winner belt [28]
10.7.2 Belt performance comparison

This kind of belt, with some minor modifications, is standard as transmission between the gear box and the rear wheel at the Harley Davidson motorcycles and the minimum distance it will last in this kind of application is 100 000 km according to a reliable source. The mechanic also informed that they used it on a bike with 115 horsepower’s and it was not any problem for the belt to take the maximum power. The actual belt was only 1 inch wide and that is only 4.4 mm wider than the 21-mm belt we proposing to use for the steering system. This information guarantee that we have supreme product, which will carry out the task for a very long time, probably the rollers full lifetime. It was necessary to adjust the belt after 5000 km on the motorcycle though, because the belt will adjust to the surface of the pulleys, but after this adjustment the tension will not demand any kind of adjustment in the whole lifetime of the belt. [25] The transmission on the motorcycle is unprotected from contamination’s but the roller steering system should be protected by covers, mostly because the danger of getting in contact with leaking hydraulic oil underneath the roller, so the lifetime will very likely be improved comparing to the motorcycle application. The use of the belt is of course very different in our case and it will not be so much wear on the belt as on the motorcycle. And the normal steering movement forces that are present when the rollers are used is not more than 7 Nm.

Figure 36. The Harley Davidson Twin cam 1450

Put more iron in your diet.
10.7.3 Parallel and angular misalignment demands

The recommendations from Gates regarding parallel and angular misalignment, which we mentioned before, is that the maximum out of line measure should be maximum 5 mm in 1000 mm centre distance or $0.25^\circ$. If these measures are exceeded, the lifetime of the belt is reduced. The angular misalignment will cause that the belt will strive for to exit the pulley track and it can also press against the steering edges, which will wear the side of the belt. This demand should not be any problem to fulfil since the steel plate structure would be assembled in a way that results in very good accuracy. [13]
10.7.4 The Sonic tension meter

Proper belt installation is essential for optimum performance and reliability of synchronous belt drives. Instead of using the “press by the finger method” to check the belt tension Gates recommends the use of a sonic tension meter. The 505C and 305D sonic tension meters analyses sound waves (natural frequencies, Hz) that are created by a blow on the belt with a tool, through a sensor. They process the input signals and give an accurate digital display of tension (Newtons). The results are far more accurate than with the former deflection method and measure the tension accurately every time. The tension testers are user-friendly, compact and store data for repetitive use. [14] (see appendix)
Of course it is possible to adjust the tension by pushing the belt outwards with a certain force and then measure how much the deflection is, which can be necessary if a tension meter is not available. There are data about this in the information supplied by Gates. (see appendix)

10.7.5 Polyurethane and the environment

[26]

Useful, helpful, practical

Polyurethanes are one of the most versatile families of specially polymers, and are used in multitude of applications. Solid or expanded, soft, flexible, semi-rigid or rigid, as slabstock foam, mouldings, film or fibers, they form the adaptable basis for an almost infinitely wide range of products. Examples include flexible foams for furniture and mattresses, rigid foams for refrigerators and buildings, micro-cellular elastomers and moulded or structured foams for such diverse applications as automotive parts of all types, shoe soles and sports articles.

Technical feasibility is not enough

Experience tells that the technological potential exist for the recycling and recovery of polyurethanes. Ultimately, however, it will be the costs that largely determine the long-term viability of these methods. As with all plastics, the most difficult task is to establish broad acceptance and a sufficiently large market for recycles.

Individual factors rather than generalised options will be the key. Specific applications and regional aspects will determine future developments. The answer to the question to how maximum economic and environmental value can be derived from post-consumer polyurethane waste will depended on three elements:

- the continued development of recycling technologies.
- investment in the infrastructure necessary to support them.
- establishment of viable markets for the recycles obtained.
**Mechanical recycling**

Mechanical (or physical) recycling of polyurethanes means one of the many forms of particle recycling. This collective term encompasses a number of very different technologies.

- **Rebounding** of flexible foam. This involves the binding of roughly 90% particles with about 10% polyurethane binders under heat and pressure.

- **Adhesive pressing** of rigid foam. (Same method as for rebonding of flexible foam.)

- **Particle bonding.** Uses from around 30 to 70% polyurethane as the matrix for any kind of particles, e.g. rubber chips for sports ground surfaces.

- **Compression moulding:** 100% particles of specific polyurethanes are recombined to produce new articles under the influence of heat, high pressure and high shear stresses.

- **Polyurethane powder** can be incorporated into new polyurethane articles at a load level of around 20%.

**Feedstock recycling/chemical recycling**

Feedstock recycling processes recover oil and gas products from mixed plastics waste streams, of which polyurethanes may be one constituent. In order to be economic, these processes must be carried out on a large scale (100,000 tons or more). The most frequently processes include pyrolysis, hydrogenation, synthesis gas generation and iron ore reduction in blast furnaces.
Small quantities, pure streams

Chemical recycling processes can be used when smaller but pure streams of particular polymers are available. By means of glycolysis it is possible to obtain liquid degradation products from polyurethanes that can be used together with new material for the manufacture of new polyurethanes.

Incineration with energy recovery

Incineration of organic waste with the recovery of energy is currently the most effective way of recycling the volume of organic material which otherwise would have to be sent to landfill. Combustion is suitable for all polyurethanes-containing products where mechanical of feedstock recycling is ruled out on ecological or economic grounds because of logistical difficulties.

Available technologies

A number of different types of equipment can be used for the combustion of plastic scrap. Rotary klin, fluidised beds, two-stage incineration and mass burning equipment have all proved effective.

Economical and environmentally sound

With a net calorific value of 24 to 30 MJ/kg, the heat content of polyurethanes is comparable to that of coal. Numerous tests runs have shown that this energy content can be recovered in an environmentally sound manner in modern plants equipped with state-of-the-art flue gas treatment facilities.

The most cost-effective the process, the better the market potential

The total of more than 125 Kt year of recovered polyurethanes should not be compared with the consumption of raw materials in 1999 in Western Europe, because long-lived polyurethanes do not enter the waste generated in 1999 was probably around 1 million tons.
Limits to mechanical and chemical recycling

While the other 50% may be technically and logistically better suited to recycling, experts have identified other obstacles, in that the market capacity for recycles may be insufficient and economics may not prove sufficiently favourable.

ISOPA (European Isocyanate Producers Association) therefore comes to similar conclusions as APME (Association of Plastics Manufacturers in Europe) does for thermoplastics: the limit for mechanical recycling is probably in the order of 15% by weight (this figure also includes chemical recycling by glycolysis).

Oil, gas and coal: multiple use instead of combustion

These valuable fossil resources can, however, be more efficiently used in plastic manufacture.
First use: manufacture of high-grade products that help to use fewer resources and to reduce the environmental burden.
Second use: at the end of the product life cycle (which can often last for several decades), mechanical or chemical recycling or incineration with energy recovery. The last process is the same as the direct use of fossil materials as a fuel, with the important difference that they have first been used for thousands of practical applications.

Towards integrated management of resources

The recycling of polyurethane waste requires a balanced approach that utilises all of the possibilities for recycling and recovery. This conclusion has also been reached by ISOPA.
Overview of the situation:

1. There is a limit to the quantity of discarded polyurethane-containing products that can be collected. The degree to which they are distributed amongst and/or combined with other materials imposes restrictions, which are very according to the individual application.
2. The recycling and recovery of collected polyurethanes by mechanical recycling and glycolysis is further restricted by the ability of the market to take up the resultant products.
3. It follows, therefore, that for a major part of post-consumer polyurethanes only two possibilities remain:
   • Use in conjunction with other commingled plastics for the recycling of petrochemical feedstocks.
   • Use together with other materials for energy recovery.

Intelligent use of crude oil

The three statements set out above with regard to polyurethane products apply equally to all others plastics. They emphasise, among other things, the importance of incineration with energy recovery for our future. Plastics are “intelligently used crude oil” – unlike fossil fuels, which are burnt for energy generation with no intermediate utilisation.
10.7.6 Belt advantages

[12][13]

To sum up the advantages with the belt comparing to the existing chain system we can settle that the belts are superior in subjects like:

- No need for lubrication.
- No elongation of the belts and therefore no need for adjustment.
- A very long lifetime comparing to the chains reduces the risk for breaks.
- A very precise and smooth mechanism.
- About the same price but much more cost effective than the chain equipment.
- Much more suitable for horizontal positioning of the pulleys.
- Reduced need for steering wheel power from the driver.
- Very easy to establish correct tension with the electronic tension meter.
- Substantially increased power rating.
10.7.7 The pulleys

The pulleys we are going to use are made of steel but there is also pulleys made of aluminium. The steel pulleys are more durable and long lasting and more suitable for our need. There are different methods for mounting the pulleys on the shafts. It is extremely important that the pulleys are installed and aligned properly. Any pulley must be correctly assembled and bolts or set screws tightened to the correct torque. Most pulleys are attached to the shaft with a tapered bushing which fits a mating tapered bore in the pulley. This type of system consists of a bushing, a pulley and often a set screw and key. Bushings come in several diameters.

The pulleys with bushings is called: Upper pulleys: 8M-38S
Lower pulleys: 8M-39S

There is limited space in the construction according to the middle shaft upper pulley so it can be necessary to install pulleys with a lock screw inserted in the centre of the pulley. It depends on the possibilities to remove the middle shaft with the upper pulley mounted, because there is very little space between the inner surface of the bearing for the driver’s turn able seat and the outer surface of the pulley.
This has to be investigated on the prototype. To achieve more space it is also possible to gain space by mounting a bearing with a larger diameter of the hole. Using a pulley with a centre positioned stopscrew, (see picture) which is set tight against the key makes it easier to tight the fastening screws for the pulleys. It is possible to reach the centre positioned screw from the side with a tool when the upper pulley is mounted on the shaft. On the other hand is it easier to mount the bushing type pulley regarding the friction between pulley and shaft. So is it possible to mount the bushing type of pulley with the limited space which is available according to the middle shaft, this method probably is the best. The pulleys with stopscrew have to be special manufactured but the cost will be about the same according to the quantity that is actual with serial production. If the centre distance between the lower pulleys is adjusted compared to the chain system, it will be possible to use pulleys with the same outside diameter and the same number of cogs as the upper pulleys.
The upper front and lower rear pulley uses only the lower steering edge to simplify removal and installation of the belt.

**Pulley with stop screw centre mounted.**

B = 30 mm

d_v = Ø15 h7

d_k upper pulleys= Ø95.17.

=38 teeth or cogs

d_k lower pulleys= Ø97.71

=39 teeth or cogs

d_B upper rear pulley (middle shaft)=Ø100

d_B front upper pulley =Ø103

d_B other pulleys=Ø106

Screw=M6x12.Flat end
As mentioned before we are using fixed shafts for the upper belt and therefore should there be a method to tighten the belt and keep it in tension. We have investigated the possibilities to solve the problem and also constructed a device. But we soon found out that the most easy and rational method is the use of a eccentrically tensioner. The function can be described like, when the tensioner is rotated around the eccentrical mounted fastening screw the belt is either slackened or tensioned. When the accurate tension has been obtained the tensioner is fixed in the right position by tightening the mounting screw. According to Gates, will the belt keep this tension through the whole lifetime. The Gates Poly Chain GT2 is recommended by the manufacturer to be tensioned from the centre and outwards and the tensioner should also have the same profile as the belt cogs. But since we have a rather unusual operation with very slow rotation the supplier recommended us to use a tensioner with flat uncrowned surface because it does not matter in this case and this solution will be much more cost effective.

10.8 The tensioner

[13][27]

When calculating the strength of the belt the pitch diameter is used, where the cord is placed.

Figure 41. When calculating the strength of the belt the pitch diameter is used, where the cord is placed.
The Mulco tension roller that we are using is equipped with two grooved ball bearings. The bearings are greased for life. The maximum long-term operation should not be performed in a temperature that exceeds 70° but short duration temperatures up to 120° is permitted so we think that this solution is usable although we have a criterion that says that the steering equipment should be able to resist 80° for long time use.

![Figure 42. The eccentrical tension roller Mulco B 40/80-0 B/E0](image)

**10.9 The double crosspin cardan joint**

As mentioned before we are proposing the use of fixed shafts except the lower rear steering valve shaft, to avoid that there is a chance that the belts misalign if unexperienced or technical not skilled persons shall handle possible service of parts related to the belts. To compensate for possible misalignment between the two front shafts there is a need for a device, which can transfer the rotating movement in a smooth way.

Demands of the angular compensation device:

- A very compact design.
- Cost effective.
- No play in the circular movement.
- It must have the same strength as the existing shafts.
- Reliable and safe
- Durable
We have made an investigation to find couplings or other devices that can supply this function. Unfortunately we have not found any satisfying solution that we can use in the very limited space that we have disposal of, except the same method that is used on the present system. The existing construction uses a single crosspin cardan joint, but since it does not use fixed shafts like our proposal it is not really the same case. We need a double crosspin cardan joint that can fully compensate the eventual misalignment that will occur if the shafts are not perfectly aligned. So this device does not have any competition from other solutions. Unfortunately we did not get the necessary information about the front steering shafts and the steering valve shaft in time from the manufacturer because there were exhibitions and other trade fairs in this time and the constructors were not available for supplying this information.

To have a logic shaft assembly we have mounted a cardan joint with a hole of 16 mm and this device supplies a strength that is approximately equal to the 15 mm middle shaft with keyway in the actual rpm range. But when the shafts are upgraded to meet the security demand of 162 Nm (see shaft information) a cardan joint with 20 mm hole will be suitable and this size provide a strength that are equal to the 20 mm shaft with keyway that will be actual. (see figure 46)

It is worth mentioning that a stop screw should be mounted to press on the key and hereby achieve a play free connection between the cardan joint and the shaft. Otherwise there is a risk that the alternating movement that occurs with a steering like this is widening the keyway and affects the fit between the surfaces of the key and keyway.

Figure 43. The double crosspin cardan joint
Figure 44. AL SERIES JOINTS

Figure 45. Measures of the Double crosspin cardan joint.

Figure 46. Tabell of moment in Nm at 100 and 200 rpm.

For double joints use the value equivalent to 90% of the mentioned torsion moments.
11. CHOICE OF DETAILS

The existing construction of shafts and steel plate structure details are kept in a similar shape because as we have mentioned before, this project is more like a modification project than a new construction project. The choice of the synchronous belt as steering transmission, which is so alike the chain transmission, does not call for any extensive modifications. We think that it is a very good idea to use the existing parts with a minimum of modifications if it is possible. Although it has been necessary to modify the plate structure parts to meet the higher demands according to the finer precision and smaller tolerances we have applied and also to achieve more space for the belt assembly with tensioner.

11.1 Demands on the details

**Product**
The steering system details must:

- be designed and suited for rational manufacturing.
- be manufactured in a way so small tolerances can be achieved.
- have a pleasant form and design if they are visible.
- be designed for long-lasting lifetime.

**Process**
The steering system details must be:

- designed to fulfil the security demands regarding stress and strain.
- designed for smooth and accurate steering movement.
- designed for a minimum of service necessity.

**Environment and surroundings**
The steering system details must be:

- harmless for the nature.
- suitable to handle the rollers oils and chemicals.
- suitable to handle a temperature of +80°C.
- resistant to the rollers great vibrations.
Human
The steering system details must be:
• safe for the driver and other persons.
• suited for comfortable and easy handling.

Economy
The steering system details must be:
• cost-effective and not be considerably more expensive than the present.
• cost-effective regarding spare parts and service
• made for long lasting use.

11.2 The shafts

We have explained about the problems that we had to get information about the material and dimensions of the shafts made by the subcontractors in Italy. The presentation of the choice of components supplies our comments about the unfortunate circumstances, which of course also applies to the construction and modification of these shafts. We thought that it should not be necessary to calculate the strength of the shafts, because we were nearly only going to replace the chain system with belts and we thought that the shaft strength already was estimated. So we were very surprised when we understood that the shafts were much too weak to handle the demands of the safety moment. Since the shafts except the middle shaft are made of both solid and pipe parts welded together and we did not have the facts about dimensions and material, we will only account for the strength of the middle shaft. We did not upgrade this shaft to the necessary diameter because we think that all the shafts should be calculated and processed at the same time to have a complete information about the strength and dimensions of the shafts. This information also includes calculating the fatigue resistance and the calculation and investigation of the natural frequencies.
11.2.1 Strength calculation of the middle shaft.

[3][4]

Security factor = 1.5, \( T = 162 \) Nm, which is the demand for the belts and the whole steering system.

\[
\tau_{\text{nom}} = \frac{16 \times T}{\pi \times d^3} = \frac{16 \times 162}{\pi \times 0.015^3} = 244.46 \text{Mpa}
\]

The width of the keyhole in the shaft is 5 mm, and the radius of the bottom corners is 0.2 mm. \( \frac{r}{b} = \frac{0.2}{5} = 0.04 \)

According to the Björks formula collection book the form factor \( K_t = 3.5 \)

\[
\tau = 244.6 \times 3.5 = 855.6 \text{Mpa}
\]

\[
\sigma = \frac{\tau}{0.6} = \frac{855.6}{0.6} = 1426 \text{Mpa}
\]

The maximum stress that the actual material (SS 2541-0.3) can take is 700 Mpa, which is the yield strength with 0.2% offset. This means that we have a tension over the double with the force of the safety demand supplied by the factory.

Security factor = 1.0 \( \implies T = 108 \) Nm.

\[
\tau = \frac{108 \times 16}{\pi \times 0.015^3} = 162.97 \text{Mpa} \quad 162.97 \times 3.5 = 570.4 \text{Mpa}
\]

\[
\sigma = \frac{570.4}{0.6} = 950.7 \text{Mpa} \quad \implies \quad \text{The tension in the shaft is far beyond the 700 Mpa, which is the limit for the shaft material, even without security factor.}
\]
11.2.2 Maximum moment for the existing middle shaft

When we selected the double crosspin cardan joint we based the selection on the strength of the middle shaft. When the steering system will be upgraded to handle the security demand of 162 Nm this cardan joint also have to be upgraded of course.

\[ \sigma_{\text{max}} = 700\text{Mpa} \]

\[ \tau_{\text{max}} = 700 \times 0.6 = 420\text{Mpa} \quad \rightarrow \quad \tau_{\text{nom}} = \frac{420}{3.5} = 120\text{Mpa} \]

The maximum moment for the existing shaft will be:

\[ T_{\text{max}} = \frac{\tau_{\text{nom}} \times \pi \times d^3}{16} = \frac{120 \times 10^6 \times \pi \times 0.015^3}{16} = 79.52\text{Nm} \]

11.2.3 The required diameter of the middle shaft

\[ d = \sqrt[3]{\frac{T \times 16}{\tau_{\text{nom}} \times \pi}} = \sqrt[3]{\frac{162 \times 16}{120 \times 10^6 \times \pi}} = 0.019m \Rightarrow d = 19\text{mm} \]

The most practical diameter to use should be 20 mm so it is easy to find suitable components like bearings and the double crosspin cardan joint, and hereby there is a very good security factor against possible failure of the shafts. When the solid shaft parts are modified to this diameter, the other parts of the Italian concept like pipe-shafts and the outer pipe for connecting holder-plates would have to be upgraded to this level also of course. This applies to all parts related to the steering system. The chosen belts and pulleys can handle the demands, as we know from the information supplied by Gates.
11.2.4 The steering column holder

We had to construct another steering column holder when we modified the shaft assembly connected to the steering wheel. The existing steering column holder is not using one of the holes made in the steel plate structure which we thought was not so good, so we constructed a holder where 4 screws are used. We consider this type safer, more cost effective and more rational to manufacture. Unfortunately will the rubber protection not fit this model. Perhaps it is possible to find something suitable, otherwise must this holder be modified to fit some existing model on the market or a tailor made rubber cover has to be made. The holder we have constructed is not complete according to the mounting parts and other, that will be necessary for a good installation of a protection device, like the existing rubber part.


11.3 The steel plate structure parts

The structure parts have to be made and assembled in much more rigorous way if the demands from Gates according to the parallel and angular misalignment shall be fulfilled. We discussed this problem with the subcontractor [29] who manufactures these parts. And he recommended us to use rectangular tabs at the outer surface of the horizontal plates, which fits in corresponding holes in the vertical plates (see the drawings of the plates). These holes or slots shall be filled with welds, and hereby will the plates be fixed to each other in an easy but very accurate and efficient way. There will of course be other weldings, which supplies the main strength to the construction.

The laser-cut plates can be made with a tolerance less than 0.2 mm [29] and the accuracy will improve a lot regarding the assembled structure if the mentioned method is used. We will not give a detailed description of the assembling procedures, but fixtures should be used to assemble and keep the plates fixed when the welding work is performed. Otherwise it will be difficult to keep the tight tolerances we have applied and the chance that there will be differences between the copies are considerable. It is worth mentioning that the holes or the slots should be longer if they are placed after the position where the plates have been bent. It is much easier to keep the tolerances at plate parts, which are straight and not bent. The subcontractor advised us to add 2 mm to the length of the hole or the slot if they are placed after a bending. The width or the height should be kept the same as on the straight parts. This method is mainly used for keeping the plates parallel to each other.

We have not performed any calculations according the strength of this plate structure because, as we have mentioned before, the construction work is more like a modification than a new construction task. But if there are some doubts about the strength of this structure, there should be investigations and calculations carried out.
11.3.1 The middle shaft-bearing holder plates. (Pos.24 Assembly 2)

When the chain assembly was used, the bearing holders for the middle shaft was not fixed in position so accurate, and the holes in the bearing holder have a considerably bigger diameter than the screws, this means that the holder can move or be placed out of the centre of the screws and the shaft will by that also be out of centre and not parallel to the other shafts. We are using a plate, which the bearing holder fits in with a small tolerance. This plate are cut with a laser like all other steel plate parts, so it should not be any problem to keep the tolerances. The bearing holder plates are put into position with a tool and then tackwelded. This tool is centred with the surfaces of the hole in the plate that the actual bearing holder is welded to. The rotating position around the centre of the hole can be set with adjustable steering plates, which gets into position by the use of the surrounding surfaces of the other plate. This centring tool can with advantage be made in brass so the welding material that jump around when the welding is performed does not stick to the tool. Unfortunately there was not time for the making of a drawing for this tool. By the help of the described equipment it should be possible to keep a very good parallel and perpendicular position of the middle shaft according to the other shafts and the steel plate structure and also regarding the centre distance between the shafts.
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[8] Hydrauliske styringskomponenter Danfoss hydraulics
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<td>Washer lower front pulley</td>
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Sonic tension meter: Model 505C

- Measurement range: 10 Hz to 1000 Hz
- Flexible sensor (cord and inductive sensor available on request)
- H 160 mm x D 26 mm x W 59 mm

Sonic tension meter: Model 305FD

- Measurement range: 10 Hz to 5000 Hz
- Flexible and cord sensor (inductive sensor available on request)
- H 208 mm x D 38 mm x W 92 mm
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**Applikation:**

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**Beräknad Gates rampdrift:**

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<td>Over Design Ratio</td>
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<td>Max effekt i systemet</td>
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<tr>
<td>Remhastighet (m/s)</td>
<td>0,05</td>
<td></td>
</tr>
<tr>
<td>Hastighetsutvisning</td>
<td>1,00</td>
<td></td>
</tr>
<tr>
<td>Beräknad axelavstånd (mm)</td>
<td>408,00</td>
<td>........</td>
</tr>
<tr>
<td>Minsta nödvändiga centrumanvstånd (mm)</td>
<td>295,08 - 410,00</td>
<td>........</td>
</tr>
<tr>
<td>Nom. axelbelast. (N)</td>
<td>2273,8</td>
<td>........</td>
</tr>
</tbody>
</table>

**Gates Rempåplågingsinfo:**

<table>
<thead>
<tr>
<th>Förepanning per rem/spår (N)</th>
<th>647,8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. intyckningskraft vid installation (N)</td>
<td>83,0</td>
</tr>
<tr>
<td>Max. intyckningskraft vid installation (N)</td>
<td>78,1</td>
</tr>
<tr>
<td>Intryckning (mm)</td>
<td>6,2</td>
</tr>
<tr>
<td>Frilängd (mm)</td>
<td>408,0</td>
</tr>
</tbody>
</table>

**Varningar:**

- Beräkningen grundar sig på inlagda data. Dim. utförs på licentiatagarens eget ansvar.
- Beräkningen förutsätter en omgivn temp mellan -54 och +65 grader.
- Drivekiva förs som standard skiva.
- Inga restriktioner för drivekiva, kontroll görs ej.
- Drivekiva förs som standard.
- Inga restriktioner för drivekiva, kontroll görs ej.
- Vid bevakning av axelbelastning tas ej hänsyn till skivornas vikt.

**Vännlig hälsning:**

Johan Lenneg
<table>
<thead>
<tr>
<th>Datum: 2001-4-23</th>
<th>DesignFlex 2K(v2) ZKQ-2801-XOX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beträffande: Dynapac, drift B</td>
<td>Gates</td>
</tr>
<tr>
<td><strong>Drivsystem</strong></td>
<td></td>
</tr>
<tr>
<td>Inget DesignFlex :</td>
<td></td>
</tr>
<tr>
<td>Skivdiameter (tänder)</td>
<td>39</td>
</tr>
<tr>
<td>Axeldiameter (mm)</td>
<td>39</td>
</tr>
<tr>
<td>Effekt drivskiva</td>
<td>104.7 Watt (100 Nm)</td>
</tr>
<tr>
<td>Service faktor</td>
<td>1.0</td>
</tr>
<tr>
<td>Varvtal drivaktivera (t/min)</td>
<td>10.00</td>
</tr>
<tr>
<td>Rambrädd (mm)</td>
<td>21.0</td>
</tr>
<tr>
<td>Remtyp</td>
<td>PolyChain GT2 / 8MG-1000-21</td>
</tr>
</tbody>
</table>

Bäddning Gates fästen i:

<table>
<thead>
<tr>
<th>Dp (mm)</th>
<th>69.31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skividentifikation/Bussning</td>
<td>69.31</td>
</tr>
<tr>
<td>Remidentifikation</td>
<td>PolyChain GT2 / 8MG-1000-21, [8275-1125]</td>
</tr>
<tr>
<td>Over Design Ratio</td>
<td>1.70</td>
</tr>
<tr>
<td>Max effekt i systemet</td>
<td>177.5 Watt</td>
</tr>
<tr>
<td>Remmächtighet (m8)</td>
<td>0.05</td>
</tr>
<tr>
<td>Hastighetsutväxling</td>
<td>1.00</td>
</tr>
<tr>
<td>Bäddning axelavstånd (mm)</td>
<td>344.00</td>
</tr>
<tr>
<td>Minsta möjliga centrumavstånd (mm)</td>
<td>822.08 - 948.00</td>
</tr>
<tr>
<td>Nom. axelbelastning (N)</td>
<td>2215.8</td>
</tr>
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**Gates Remspänning Info.**

<table>
<thead>
<tr>
<th>Förspänning per remispår (N)</th>
<th>645.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. intryckningskraft vid installation (N)</td>
<td>62.4</td>
</tr>
<tr>
<td>Max. intryckningskraft vid installation (N)</td>
<td>76.0</td>
</tr>
<tr>
<td>Intryckning (mm)</td>
<td>8.9</td>
</tr>
<tr>
<td>Från längd (mm)</td>
<td>344.0</td>
</tr>
</tbody>
</table>

**Varningar**

- Beräkningar grundar sig på inläggda data. Dim. utförs på licenstagenas eget ansvar.
- Beräkningen förutsätter omgivning mellan -50 och +85 grader.
- StDev hjula för drivskivan är tillgängligt.
- StDev drivskiva och tillgänglig för driven skiva.
- Vid beräkning av max belastning tas ej närsyn till skivornas vikt.

Vänliga hälsningar

Johan Lennart
All not lift framed measures shall be kept as on the original Svodala Construction drawing.

<table>
<thead>
<tr>
<th>Sheet</th>
<th>Rev.</th>
<th>Status</th>
<th>Sheet no.</th>
<th>Drawing no.</th>
<th>Scale</th>
<th>Drawn by</th>
<th>Checked by</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>123</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- All dimensions are in millimeters (mm).
- All tolerances are ±0.1 mm.

**Drawing Scale:**
- 1:50

**Legend:**
- Solid lines: Construction lines
- Dotted lines: Reference lines
- Thick lines: Structural lines

**Material:**
- Steel
- Painted

**Marking:**
- Black ink: Indication of main features
- Red ink: Indication of additional features

**Approval:**
- Initialled by: [Name]
- Date: [Date]

**Revision:**
- Revision mark: [R1]

**Control:**
- Control number: [123]
<table>
<thead>
<tr>
<th>1</th>
<th>SS 1989, zincified</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No.</strong>, <strong>Art.:</strong></td>
<td><strong>Title:</strong> Steering column locking handle washer</td>
</tr>
<tr>
<td><strong>Högskolan i Karlskrona/Ronneby</strong></td>
<td><strong>Inst. för Maskinteknik</strong></td>
</tr>
<tr>
<td><strong>Dynamac</strong></td>
<td><strong>1:1</strong></td>
</tr>
</tbody>
</table>

**Diagram:**
- R50
- D11

**Sheet:**
- Size: 300mm x 420mm
- Orientation: Portrait

**Scale:** 1:1
| Artikelnr | Artikelmedium | Artikelnr | Referens
|----------|---------------|-----------|-----------
| 1        | SS 1050       |           |           

| Artikelmedium | Artikelnr | Referens |
|---------------|-----------|-----------
| SS 1050       |           |           

**Title / Benämning:**
Höger tension wheel

**Institution:**
Högskolan i Karlskrona/Ronneby
Inst. för Maskinteknik

---

Examination Thesis
<table>
<thead>
<tr>
<th>Nr.</th>
<th>Antal</th>
<th>Titel / Beskrivning</th>
<th>Material / Dimensio</th>
<th>Artikelnr / Referens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Washer lover front pulley</td>
<td>S3-100 2798-1 m</td>
<td>1:1</td>
</tr>
</tbody>
</table>

**Notera:**
- Hägskolen i Karlskrona/Ronneby
- Inst. för Maskinteknik

**Diagram:**
- Diameter: 30 mm
- Diameter: 21.5 mm