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Mini genset for vibration measurement

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Bachelor´s thesis

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BACHELOR'S THESIS

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Title: *Mini genset for vibration measurement*

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Abstract

The Bachelor's thesis work was made at Wärtsilä Service, Vibration Environmental and Measurement Technologies in Runsor, Vaasa. The purpose of the work was to design and build a mini genset that can be used to measure vibration and torsional vibration. It will be used as a demonstration machine to practise and teach how vibration measurement equipment works. The reason why this mini genset is needed is that there is none that meets these requirements in a store. Only the mechanical part, to find parts and to build them together, has been carried out. A vibration measurement is presented at the end of the thesis. This measurement was made to see if the mini genset works and if there are some vibrations.

Language: English

Key words: vibrations, mini genset, torsional vibrations, vibration simulator, demonstration machine

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EXAMENSARBETE

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Utbildningsprogram:	Produktionsekonomi
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Titel: *Minigenset för vibrations mätningar*

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Abstrakt

Detta examensarbete gjordes vid Wärtsilä Service, Vibration Environmental and Measurement Technologies i Runsor, Vasa. Syftet med detta examensarbete var att designa och bygga ett minigenset som kan användas till att mäta vibrationer och torsionsvibrationer. Det kommer att användas som en demonstrationsmaskin för att öva och lära ut hur vibrationsmätningsutrustning fungerar. Anledning till att detta minigenset behövs är att det inte finns något som motsvarar dessa krav i en affär. Det var bara den mekaniska delen, att hitta delar och bygga ihop dem, som har gjorts. En vibrationsmätning presenteras i slutet av examensarbetet. Denna mätning gjordes för att se om minigensetet fungerar och om det finns några vibrationer.

Språk: Engelska

Nyckelord: vibrationer, mini genset, torsionsvibrationer, vibrationsimulator, demonstrationsmaskin

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1 Introduction

The reason why this work was chosen to become my Bachelor’s thesis was that I worked at Wärtsilä as a trainee in the summer of 2011 and after the summer I continued with the Bachelor´s thesis work.

I did my Bachelor´s thesis at Wärtsilä Technical Service, Vibration, Environmental and Measurement Technologies. Mr. Matias Palmujoki has supervised my work at Wärtsilä and Roger Nylund has been my supervisor at Novia. The goal of this Bachelor´s thesis was to design and build a demonstration machine for testing vibration and torsional vibration. The machine will be used for measurement training and also for testing new measurement equipment.

To get a fully operational demonstration machine I needed to find suitable parts and also design bracket that fit to the parts.

2 Purpose of the Bachelor’s thesis

The purpose of the thesis is to build and design a mini genset that can be used to measure vibration and torsional vibration. This mini genset will work as a testing and demonstration machine. It can for example be used to test new equipment but also for educational purposes, to teach and learn how the measurement equipment works.

A generating set (or genset) consists of an internal combustion engine and a generator mounted together on a base frame, e.g. Wärtsilä 34DF generating set. The idea is that this mini genset will work as a simulator for a real Wärtsilä genset, for vibration measurements.

Only the mechanical work, i.e. finding parts and building the genset, will be carried out. There will also be a measurement at the end of the thesis to see what the vibration results will be like, if there was some vibration or not.

The reason why this mini genset is custom designed, is because there isn´t any mini genset in the regular store that meets the requirements and would be suitable.

3 Company

Wärtsilä is a global leader in complete solutions for the marine and energy markets. Wärtsilä operates in Europe, Asia, the Americas and Africa. The company employs over 17,000 employees in 160 locations in 70 countries around the world. The company operates in three business areas: Ship Power, Services and Power Plants. Ship Power is the department where they focus on solutions at sea, while Power Plants focus on electricity producing engines on the mainland. Service takes care of the lifecycle of the engines. They offer the customers for example advice, spare parts and repairs. (1)

In Finland Wärtsilä has 3,400 employees and is located in Vaasa, Helsinki (headquarters), Turku and Espoo. In Vaasa Wärtsilä has 2,900 employees and the main R&D center for Wärtsilä 4-stroke engines is located there. The production for Wärtsilä W20, Wärtsilä W32, Wärtsilä W34DF, Wärtsilä W34SG is also located in Vaasa. The locations where Wärtsilä operates in Vaasa are in the city centre and in Runsor (2)

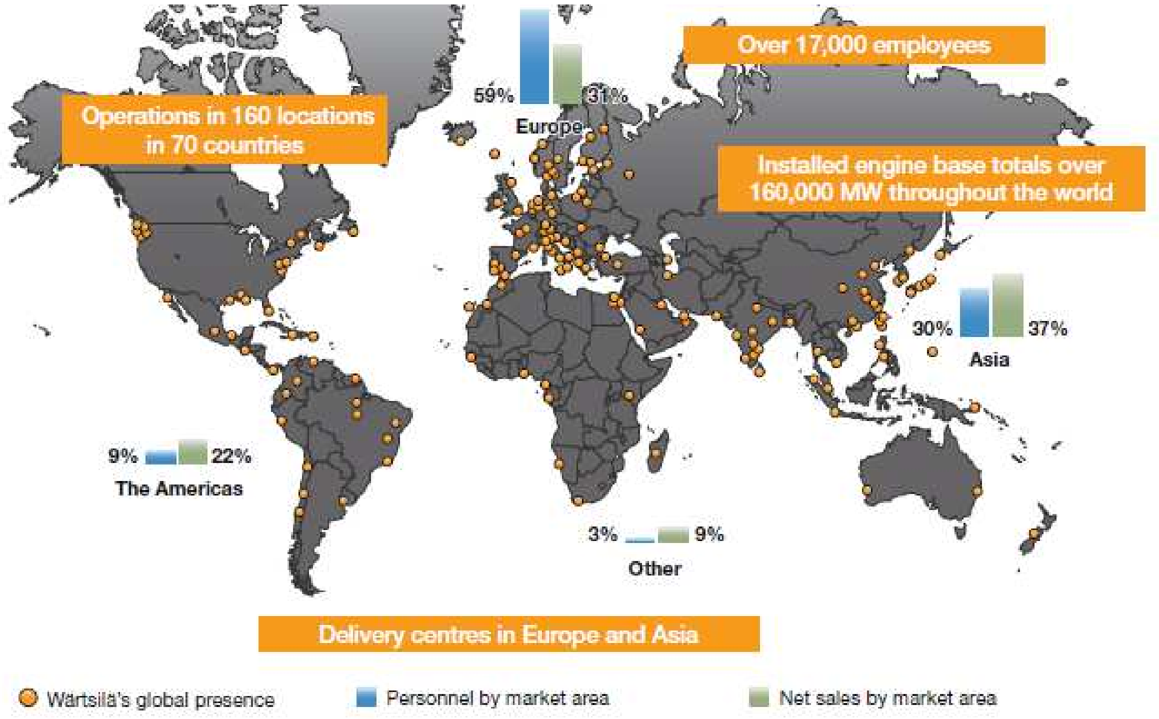


Figure 1. Wärtsilä´s global operating map (1)

4 Theory

4.1 Vibration basics

Vibration refers to mechanical oscillations about an equilibrium point. The oscillations may be periodic, such as the motion of a pendulum, or random such as the movement of a tire on a gravel road. Vibration is occasionally desirable, for example the motion of a tuning fork. More often vibration is undesirable, for example the vibrational motions of engines or any mechanical device in operation are typically unwanted. There are two different types of vibration, free vibration and forced vibration. (3)

Free vibration occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely. Examples of this type of vibration are pulling a child back on a swing and then letting go or hitting a tuning fork and letting it ring. The mechanical system will then vibrate at one or more of its “natural frequencies” and damp down to zero. (3)

Forced vibration is when an alternating force or motion is applied to a mechanical system. An example of this type of vibration is the vibration of a building during an earthquake. In forced vibration the frequency of the vibration is the frequency of the force or motion applied, but the magnitude of the vibration is strongly dependent on the mechanical system itself. (3)

Why are vibration measurements required? The measurements need to be performed because vibration can harm or demolish an engine or its components. There are two occasions on which vibration measurements are often required. The first occasion is during or just after commissioning and the second occasion is when vibration problems occur. (4)

4.1.1 Overall measurement

There are several different techniques that can help in solving vibration problems. The different techniques are visual inspection, measuring vibration levels and measuring vibration spectrum. Visual inspections are important, but this is a limited technique because the human eye is not able to see vibrations of a higher frequency than roughly 50 Hz. (4)

4.1.2 Wärtsilä measurement procedure

The first thing to do is to measure overall vibration levels. This gives an indication of the vibration severity but seldom gives an answer to the underlying vibration problem that is causing the vibration. Overall vibration levels are sufficient as a reference measurement and for engine monitoring purposes, but for problem solving also vibration spectra are needed. At Wärtsilä the most common vibration instruments are B&K 2513 and EM 83.0 vibration scanner. (4)

What can cause extensive vibration on an engine?

- Misalignment, main coupling failure: this kind of problems cause first and second order vibration.
- Heavy misfiring: this often causes first order vibration.
- Flexible mounting problems: first order vibration is extensive.
- Higher engine order vibration problems: broken or loosened steel structures.

The excitation frequencies are normally expressed as harmonic orders of the engine running speed. The frequency of the k^{th} order is then k*n/60 Hz, where n is the running speed of the engine in unit [rpm].

An example of how to calculate the engine harmonic order:

Engine speed: 750 rpm
Engine order 1.0 = 1.0 x 750rpm / 60= 12.5 Hz
Engine order 2.0 = 2.0 x 750rpm / 60= 25.0 Hz

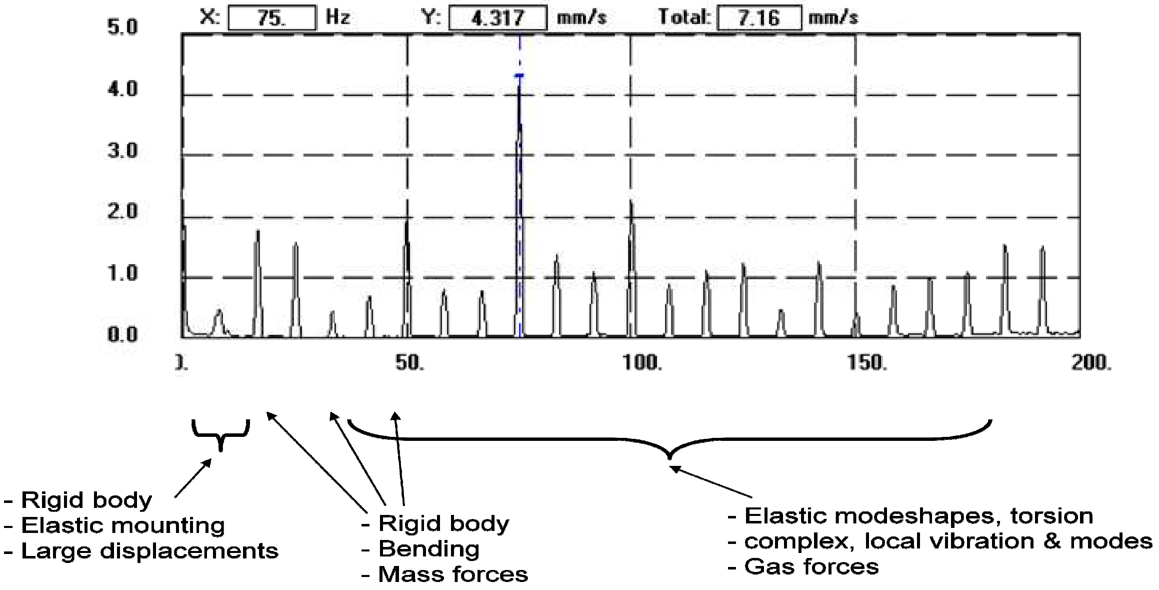


Figure 2. A typical vibration spectrum measured on a diesel engine. **(4)**

The simplest vibratory system is an undamped spring-mass combination. The free vibration of this system can be described by formula 1. (5)

Formula 1:

$ma+kx=0$, where

a is acceleration
x is the amount the spring is stretched
ma expresses the force produced by the oscillating mass
kx describes the counteracting force in the spring

The natural frequency of the system in figure 3 is calculated by formula 2:

Formula 2:

$f = (1/2\pi)\sqrt{(k/m)}$, where

f is frequency
k is stiffness of the spring
m is the mass of body

(4)

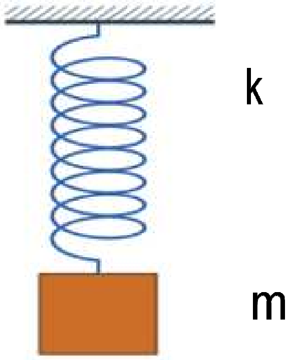


Figure 3. An undamped spring-mass combination. (5)

4.2 Vibration damping

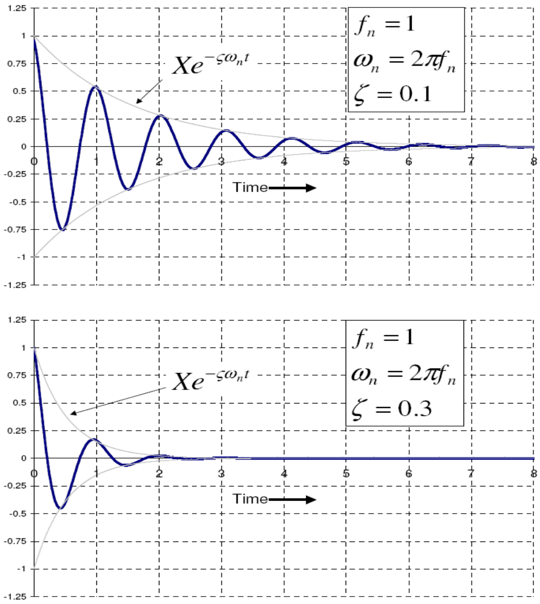
To damp the vibration of an engine you need to install a damper, which will protect the engine and surrounding parts from taking damage from vibrations.

In figure 4 there is a graph showing free vibration with damping. The degree of damping depends on the material, the external damping arrangements and the design. Formula 3 for free damped vibrations is:

Formula 3:

$\boldsymbol{m\ddot{x} + c\dot{x} + kx = 0}$, where

c is damping coefficient



(5)

Figure 4. Free vibration with damping (5)

4.3 Operating deflection shapes

An operating deflection shapes (ODS) analysis is used to determine the vibration pattern of a structure under given operating conditions. Vibration measurements are performed at different points and directions on the structure and the vibration pattern can be shown as an animated geometry model of the structure or listed in a shape table. (6)

Any ODS is a combination of the forcing function acting on the structure and the dynamic properties of the structure. The forcing function depends on the operating conditions, which for machinery could be influenced by e.g. engine speed, load, pressure, temperature and flow. Ambient forces from waves, wind and traffic might also apply for civil engineering structures. (6)

The ODS analysis can be divided into three types: Time ODS, Spectral ODS and Run-up/down ODS.

Time ODS is used to investigate the vibration pattern of a structure as a function of time. In contrast to Spectral ODS and Run-up/down ODS, where the vibration pattern of a single frequency or order is investigated, Time ODS includes all frequencies in the analysed frequency range. (6)

Spectral ODS is used to investigate the vibration pattern of a structure for a specific frequency or order component. For frequency component investigations, FFT analysis is used and the conditions must be stationary. For order component investigations, an order analysis is used to eliminate “smearing” of spectral components in cases of almost stationary conditions. (6)

Run-up/down ODS is used to investigate the vibration pattern of a structure for specific order components as a function of rotational speed. The order components can either be defined beforehand (pre-slices) and/or taken out as slices from e.g. contour plots (post-slices). Run-up/down ODS is very useful for relating a structure’s noise and vibration behaviour to the rotational parts of an engine. (6)

4.4 Torsional vibration

Torsional vibration is an angular vibration of an object, for example a shaft along its axis of rotation. Torsional vibration is often a problem in power transmission systems using rotating shafts or couplings, where vibration can cause failures if not controlled. (7)

In an ideal power transmission system using rotating parts, the torques applied or reacted are smoothly leading to constant speeds. In reality this is not the case. The torques generated may not be smooth (e.g. internal combustion engines), or the components being driven may not react to the torque smoothly. The components transmitting the torque can generate non-smooth or alternating torques e.g. worn gears, misaligned shafts. Because the components in power transmission systems are not infinitely stiff, these alternating torques cause vibration about the axis of rotation. (7)

Torsional vibration is a problem in the crankshafts of engines because of several factors:

- Alternating torques are generated by the slider-crank mechanism of the crankshaft, connecting rod, and piston.
    - The motion of the piston mass and connecting rod mass generate alternating torques often referred to as inertia torques.
    - The cylinder pressure due to combustion is not constant through the combustion cycle.
    - The slider-crank mechanism does not output a smooth torque even if the pressure is constant, e.g. at top dead centre there is no torque generated.
- Engines with several cylinders can have very flexible crankshafts due to their long length.
- There is inherently little damping in a crankshaft to reduce the vibration.

If torsional vibration is not controlled in a crankshaft, it may cause failure of the crankshaft or any accessories that are being driven by the crankshaft. This potentially damaging vibration can be controlled by an installation of: (7)

- Tuning mass

  A tuning mass is a rotating disc (small flywheel) that changes the natural frequency of the system. Typically located at the free end of the engine, but it can also be used in other locations, e.g. close to a coupling for tuning the coupling natural frequencies. (8)

- Viscous damper

  A viscous damper is a seismic mass surrounded by silicon oil and enclosed in a housing. It changes (lowers) the natural frequency of the system and gives additional damping. It is typically located in the free end of the engine. (8)

- Tuned damper

  Tuned mass damper stabilizes violent motion caused by harmonic vibration. A tuned damper reduces the vibration of a system with a comparatively lightweight component so that the worst-case vibrations are less intense. (8)

- Flywheel

  A flywheel is a rotating mechanical device that is used to store rotational energy. Flywheels have a significant moment of inertia, and thus resist changes in rotational speed. It is used to reduce speed fluctuations and to tune first torsional mode of crankshaft. (8)

- Couplings

  There are many different types of couplings, e.g. flexible coupling, rubber coupling, steel spring coupling and hydrodynamic slip coupling. The primary purpose of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both. They also reduce the transmission of shock loads from one shaft to another. (8)

4.4.1 Torsional vibration measurement

The torsional vibration measurements are performed when seen necessary, e.g. with new engine configurations or when required by customer. The measurement methods are either angular amplitude measurements or strain measurements. The measurements strive to determine the location of resonances (natural frequencies) and the amplitude of torsional vibrations. The measurement tools that are used at Wärtsilä to measure torsional vibration are OROS and encoders. (9)

5 Design of mini genset

To get a fully functional mini genset and to make it run, a motor is needed that drives everything around. An electrical motor was chosen because the mini genset will be inside and therefore an internal combustion engine was not a good alternative. The most important feature of the electrical motor was that the speed range needs to be 50-1200 rpm. This is because the rpm on the electrical motor should be equal to the rpm on a real Wärtsilä motor, i.e. oscillations will be on the same frequency area and a frequency analysis is used when vibration measurements are made.

Another requirement was that the electrical motor needs to be user controlled, because then the speed of the motor can be adjusted and measurements can be performed at different speeds. This will be solved with an AC drive, which makes the motor user controlled.

A shaft that connects the other components is also needed. The dimension of this shaft was 12 mm. The choice of 12 mm is because the shaft will hold and not break down. It is also a compromise between the electrical motor shaft, 14 mm, and the trimmer motor shaft, 10 mm. To connect the shaft to the electrical motor and trimmer, two stiff couplings are needed and also a soft coupling, which will come in the middle of the mini genset.

Then there must be brackets to the trimmer motor, encoders and bearings as well as a base frame that everything will lie on.

It would also be good to get the whole mini genset as light as possible and it should not be too big either. It will be easier to handle the mini genset, if it is not too big and heavy. Thereby it will be possible to move it, if necessary. Some other specifications are:

- Dynamic twist:

  Dynamic twist will vary all the time in this case, because the drive of a trimmer motor will generate torsional vibration.

- Vibration testing should be possible:

  This is one of the reasons why the whole mini genset is built, as the mini genset will be used to measure vibration. The mini genset needs to vibrate.

- Static twist, possibility to regulate static twist by turning encoder during run, twist angle to be +/- 15°:

  The possibility to regulate the static twist by turning encoder is there, because we want to measure the static twist. To be able to measure the static twist it needs to be changed, in this case the encoder needs to be turned. The angle +/- 15° has been chosen, because this is the maximum a real Wärtsilä engine coupling reacts.

- Encoders on both sides of coupling:

  Encoders on both sides of coupling are needed so that we can measure the twist in the couplings.

- Flexible mounting:

  Some rubber elements will be put under the base frame. They are there to simulate flexible mounting on a real genset.

- Mechanical indicator for static twist:

  A mechanical indicator is needed to see how many degrees the encoder is turned during the measurement.

- Look-like common base frame, material: steel:

  The choice of steel is because the base frame needs to be handling the weight and vibration without bending. The measurement will be easy if it has the same look as a common base frame.

- Safe operation, hand and finger protection and emergency stop:

  This is needed to protect the person who performs something on the mini genset, if something unpredictable should happen.

- Constant speed switch on HMI:

  This is needed to operate the nominal speed directly without adjusting it on the buttons on the console.

- RPM indication to be designed:

  An RPM indicator is needed so that it is possible to see the current RPM of the mini genset when driving it.

Figure 5 shows the final drawing and this is what the demonstration machine will look like. The dimensions in the drawing are in actual size and the unit of measurement is millimetre. The electrical motor comes to the left with a size of 176 mm. This is the biggest item. After the electrical motor follows the stiff coupling that connects the electrical motor with the shaft. After that the adjustable encoder with brackets comes, this is the part that is 78 mm. Bearings are included in both encoder brackets.

Then a soft coupling comes in the middle, with a size of 136 mm. To the right the static encoder with bracket comes. After the static encoder comes the other stiff coupling, which connects the trimmer motor and the shaft. Then rightmost the trimmer motor with its both brackets comes. The final length of the whole mini genset will be 854 mm.

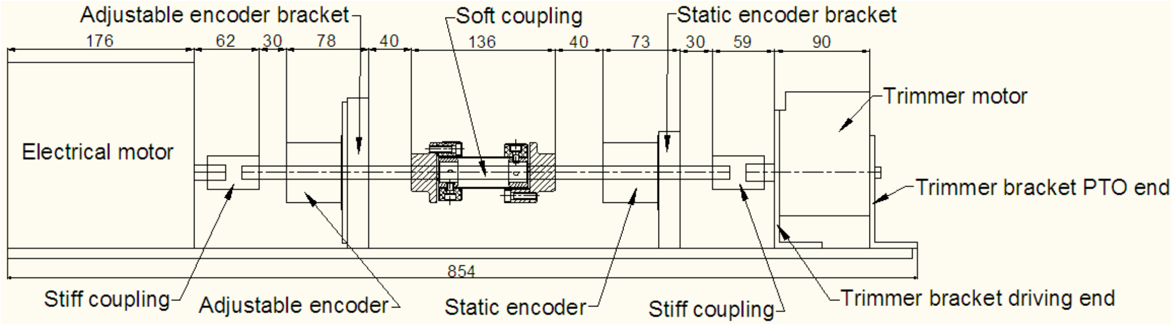


Figure 5. Final drawing of the demonstration machine

5.1 Electric motor

To get the whole demonstration machine to run, an electrical motor was necessary. The motor that was chosen is a VEM K21R 71 K6. It is a small motor with a power of 0,18 kW. It was the heaviest part of the demonstration machine with a weight of 7,4 kg.

This motor is the smallest electrical motor in VEM´s range, 180W. It also meets the RPM requirements and with the 6 poles design, the nominal speed is approximately 930 RPM. The supplier was also asked if it is possible to drive the motor with a higher RPM, to meet speed requirements, like it says in the manual. The supplier approved this.

Figure 6. VEM K21R electrical motor **(10)**

5.2 AC drive

To control the speed of the electric motor there must be an AC drive. With the AC drive the speed is controlled by changing the frequency of the electrical supply to the electric motor. The 3-phase voltage in the electrical grid connected to a motor creates a rotating magnetic field in it. The rotor of the electrical motor will follow this rotating magnetic field. An AC drive converts the frequency of the network to anything between 0 and 300 Hz or even higher, and thus the drive controls the speed of motor proportionally to the frequency. The AC drive also makes it possible to change the direction of rotation. (11)

The AC drive that was decided to be used was the Vacon 10 AC drive. Vacon 10 was chosen because it is a small and compact AC drive, simple to use and it also has all the functions needed. There are different sizes of the Vacon 10. The one that was chosen is one of the smallest. It can handle up to 0,25 kW, which suits because the electrical motor is 0,18 kW and there is no need of any bigger AC drive. It was also bought from the same place as the electrical motor and it was recommended for the electrical motor that was chosen. (11)

Figure 7. Vacon 10 AC drive **(11)**

5.3 Trimmer motor

The first plan was to look for a small compressor, but there were no suitable ones. Most of them were too big or did not meet the requirements, thus something else than a compressor had to be found. A trimmer motor would be suitable. It looks like a motor and the dynamic pressure can also be measured by removing the spark plug. The decision was therefore to look for a trimmer motor.

Two trimmers were dismounted before the suitable trimmer motor was found. The trimmer motor that was chosen has a shaft on both sides of the motor. This is because now it is possible to e.g. have an encoder on the non-driving end of the shaft later, if needed.

The trimmer that was bought was the Stiga SB 26 JD. This trimmer met the requirements to have the shaft in both ends and was at a fair price range. The trimmer was dismounted and the only thing we needed was the motor**.**

5.4 Encoder

An encoder can serve as a measuring sensor for rotary motion, angular velocity and also for linear motion, when used in conjunction with mechanical measuring standards such as lead screws. (12)

An encoder can be of two types, incremental or absolute. An incremental encoder is a type of sensor that is often installed on an electric motor and used to provide feedback on the motor's speed. Absolute encoders on the other hand are used to indicate an exact position for some kind of motion. The two encoders that will be on both sides of the soft coupling are incremental encoders, because we want to measure the speed. There also has to be a hollow through encoder, which can be mounted anywhere on the shaft and not only at the end of the shaft. (13)

5.4.1 Encoder selection

After some searching there were two encoders that were suitable, i.e. Leine & Linde RHI 503 57 and Heidenhain ERN 430. Both are incremental rotary encoders with hollow through shaft and there were no big differences between these two. Because of the simple installing and mounting, the Heidenhain ERN 430 was chosen.

Figure 8. Heidenhein ERN 430 encoder (14)

Heidenhain ERN 430, which you can see in the picture above, is a rotary encoder with integral bearings and stator mounted couplings. It operates by photoelectric scanning. (14)

It is an incremental hollow through shaft encoder and has an incremental rotary encoder. The current position is determined by starting at a date and counting measuring steps, or by subdividing and counting signal periods. Incremental encoders from Heidenhain feature reference marks, which must be scanned after switch-on to re-establish the date. (14)

In figure 9 you can see how the encoder works. The incremental signals are transmitted as the square-wave pulse trains U_{a1} and U_{a2}, phase shifted by 90° elect. The reference mark signal consists of one or more reference pulses U_{a0}, gated with the incremental signals. These signals will be sent to an equipment that translates the signals into RPM. (15)

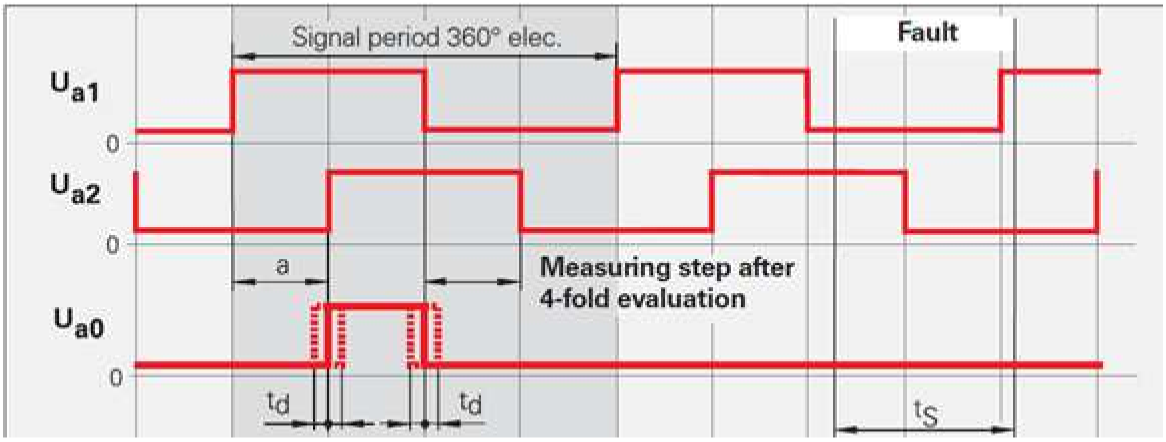


Figure 9. The ERN 430 square-wave signals. **(15)**

5.5 Couplings

To get a functional mini genset and to meet the requirements, there is a need for three couplings. One coupling that connects the trimmer motor to the shaft and one coupling that connects the electrical motor to the shaft. These two couplings need to be torsionally stiff and the couplings should have ability for radial and axial movements. This is needed because the shaft of the mini genset will not be perfect aligned with every components and there will probably be some radial and axial movements. The last coupling will be different than the other two, this will be in the middle of the mini genset and it will be a flexible coupling. But this coupling also needs flexibility in any direction.

5.5.1 Torsional stiff coupling

There are many different coupling types. After some research and after recommendation by the electric motor manufacturer there were two possible ones, both were from KTR. One is the ROTEX GS (figure 10) and the other is TOOLFLEX (figure 11).

Figure 10. KTR ROTEX GS coupling **(16)**

Figure 11. KTR TOOLFLEX coupling **(16)**

They are both backlash free couplings and they have a compact design and are easy to assemble. With the ROTEX GS you can adjust the damping through different elastomer hardness of the spiders. The spider is the one that is red in figure 10**.** The TOOLFLEX is suitable if higher torsional stiffness is required, the ROTEX GS has less torsional stiffness. (17)

Due to the high stiffness of the TOOLFLEX the torsion angle is very low under torque. However, contrary to the ROTEX GS a damping of torsional vibrations is not possible. So KTR TOOLFLEX M coupling was preferred over ROTEX GS coupling. There was also a KTR TOOLFLEX S design, but the KTR TOOLFLEX M design was more flexible than the S design and so the KTR TOOLFLEX M designs were chosen. (17)

TOOLFLEX is a metal bellow-type coupling. The metal bellow compensates for axial, radial and angular displacements. At the same time its geometric shape allows for high torsional stiffness and a low mass moment of inertia. The shaft hub connection is a clamping hub that is easy assembly by a radial clamping screw. (16)

5.5.2 Torsional soft coupling

The centaflex-A coupling from Centa is a highly flexible coupling. The coupling has high elasticity and considerable flexibility in any direction (radial, axial, angular) with low counter forces on shafts and bearings. The shafts do not therefore have to be aligned accurately. The choice felt on the centaflex A coupling because it was the softest coupling from Centa and Centa is also already used as a supplier to Wärtsilä. See the table in appendix 3 where the stiffness and damping of the centaflex-A coupling can be seen. The size of the centaflex is 12 mm. (18)

Figure 12. The Centaflex A coupling mounted at the shaft

6 Assembly

6.1 Design of brackets

The brackets to trimmer motor, couplings, bearings and the base frame were designed by myself and manufactured at a local company. The drawings were made in AutoCAD. The brackets will carry the encoders, the trimmer motor and the bearings so it will be at the same height as the electrical motor shaft. This is because the electrical motor already has feet to stand on, which will come against the base frame bracket. The brackets to the other components were proceeding from the shaft of the electrical motor and the shaft is 71 mm above motor foot level.

6.1.1 Trimmer motor bracket

To get the trimmer motor steady one bracket on each side of the trimmer motor was needed. There were already screw holes on the trimmer motor so the brackets needed to be designed after that. The material of the trimmer motor bracket was an L-profile 150x50x5. This was because the L-profile fits well and it is cheaper and demands less work than other methods. The height of the trimmer bracket was 130 mm high and the width of it was 155 mm. The foot of the trimmer bracket will be 45 mm long and there were two holes in it.

A problem occurred with the trimmer motor bracket when the base frame was designed. The hole in the middle where the shaft will come through was not centred. So when the base frame was designed, one of the sides on the trimmer bracket didn´t fit inside the base frame. The solution was to cut off the part that is outside the base frame bracket, but higher up there was a hole for a screw and this hole needed to be there. As you can see in figure 13, the foot and some part of the side were cut off but the screw hole was there. The hole needs to be there because it will help the trimmer motor to remain stable at that side.

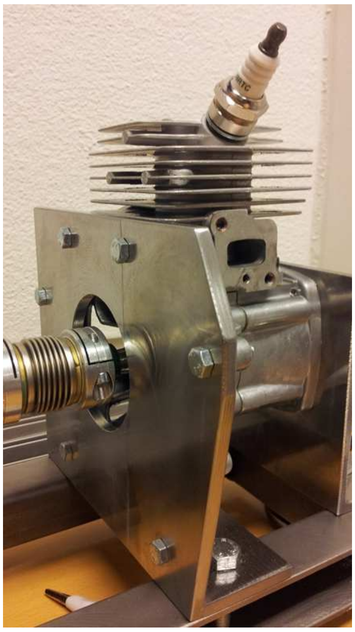


Figure 13. Trimmer motor and brackets mounted together.

6.1.2 Encoder brackets

As there are two encoders there will also have to be two encoder brackets. These encoder brackets will not have the same design, because the requirement of one encoder was that it should be possible to regulate static twist by turning the encoder during run. There must also be a mechanical indicator on that encoder bracket and the twist angle has to be +/-15°. The bearings also need to be included in both encoder brackets.

The encoder bracket that does not need to be turnable is formed as a rectangle and the thickness is 20 mm. It was made of aluminium and it was fastened to the base frame by two screw holes underneath**.** The hole in the middle was made for the bearing and this hole needs to have the tolerance K7, so that the bearing will match the hole perfect and stay in the right place.

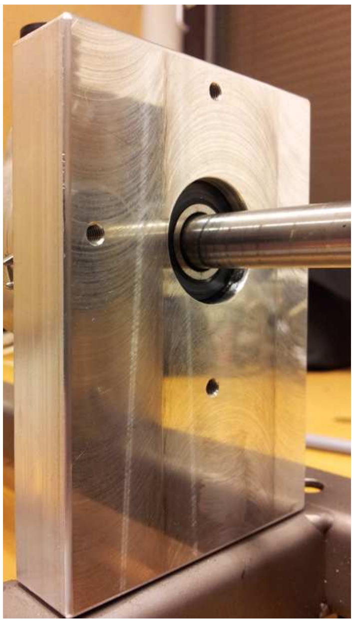


Figure 14. Static encoder mounted on the base frame.

The second encoder bracket, which was the adjustable one, has a rectangle form with a half circle above (see appendix 7). The reason was that there will be a mechanical indicator at the top of the bracket. Three holes have been added in order to fasten the second part that was needed for this bracket. That part is a round circle with a handle made of aluminium. It is designed so that there is a possibility to turn the encoder +/- 15°. To make it possible to turn the encoder, the second part (the one that is round and where the encoder is fastened) will be fastened by three screws that have a rubbery o-ring against the rounded bracket with handle (see figure 15)**.** When the o-ring is there, you can turn the encoder during run and you don´t need to adjust the screw when you want to turn the encoder. The tolerance of the bearing hole is K7 and the thickness of the parts together is 25 mm.

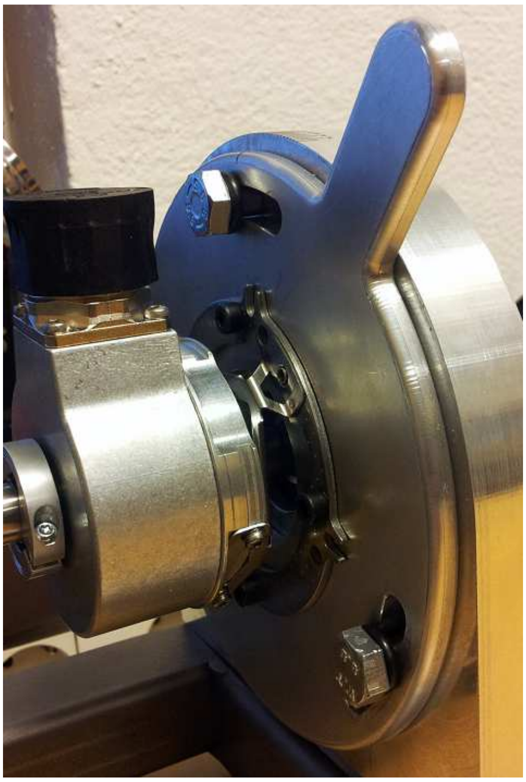


Figure 15. The adjustable encoder bracket with encoder

The choice of aluminium is because it is easier to process and it is lighter than steel.

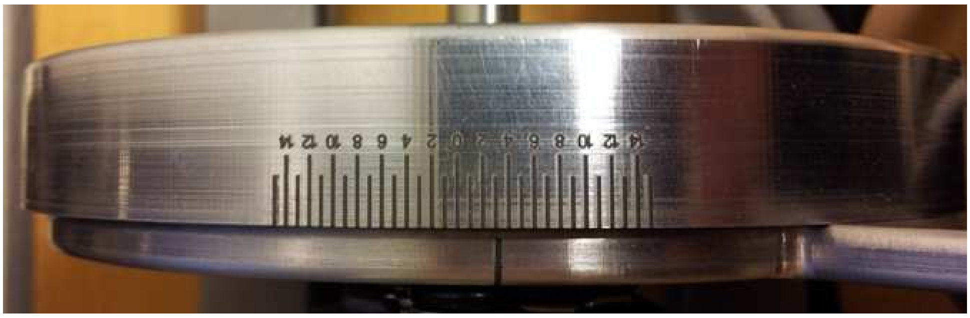


Figure 16. Adjustable encoder bracket with mechanical indicator

6.1.3 Bearing

To make it possible to have a bearing in the encoder brackets it must be a bearing that can take radial and axial loads acting in both ways. The bearings needed for the encoder brackets are double row angular bearings.

A single angular contact ball bearing has raceways in the inner and outer rings that are displaced with respect to each other in the direction of the bearing axis. This means that they are designed to accommodate combined loads, i.e. simultaneously acting radial and axial loads. Meanwhile the double row angular contact ball bearings correspond in design to two single row angular contact ball bearings, but they take up less axial space. They can accommodate radial loads as well as axial loads acting in both directions. They provide stiff bearing arrangements and are able to accommodate tilting moments. (19)

The choice felt on a bearing from SKF. The type is SKF 3201 A-2RS1TN9/MT33. This is a double row angular contact bearing with seal on both sides. This bearing makes it possible to fit the bearing into the encoder bracket.

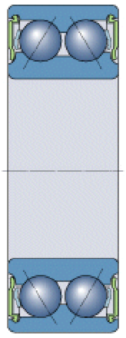


Figure 17. Double row angular contact bearing **(19)**

6.1.4 Base frame

The base frame was designed so that it consists of a welded U-profile 30x30x3 mm and the material was steel. It was designed like a rectangular with two long u-profiles on the side and a small one at the end and inside. There was also a steel plate, welded across where the electrical motor was. This is because the electric motor´s feet are bigger than 30 mm and with the steel plate there the electrical motor will be more stable.

The U-profiles in the middle are measured and designed so that the brackets will come in the right place. It is also possible to switch places on the two encoders. For further information about the dimension see appendices 10-16.

The length of the base frame is 854 mm and the width is 140 mm. The weight of the whole base frame is approximately 3,8 kg.

The reason for choosing the U-profile was because it is easy to build, the U-profile needs to be sawed to get the right dimension and then the different parts need to be welded together. With the U-profile design the base frame will be stable for the weight of the electrical motor and the bracket. The base frame will not be bent so easily.

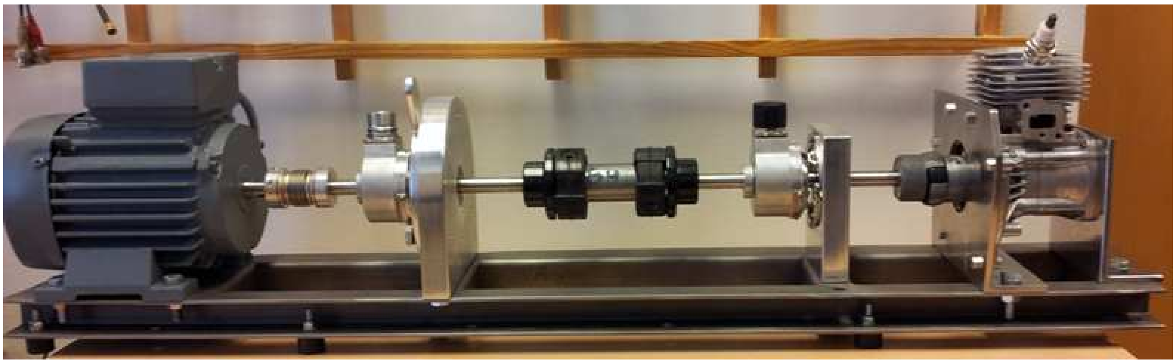


Figure 18. All parts mounted together on the base frame.

6.1.5 Control board

The mini genset also has a console from which it can be operated. On the console there is an emergency button and a start/stop button. There is also a button to adjust the speed and also the direction of the electrical motor (forward/reverse) with. The display on the console shows the RPM of the electrical motor.

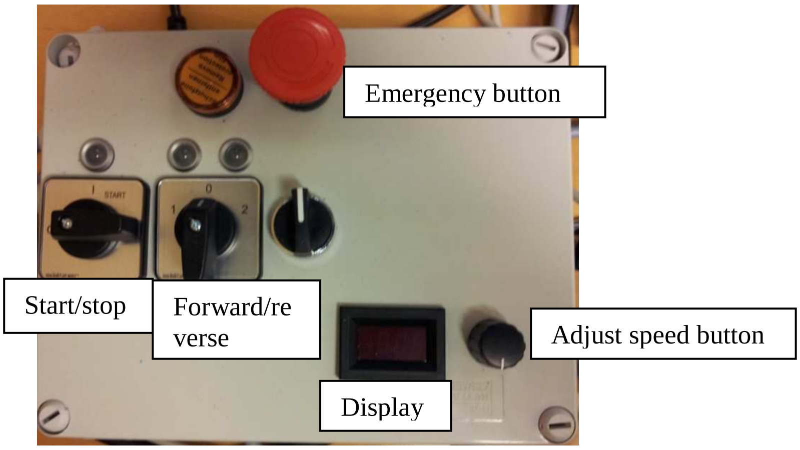


Figure 19. Control board

7 Test run

The first run was made to check that everything worked and to see if there were some problems. The test run was successfully done without problems.

When the measuring test runs were performed, the coupling that connects the trimmer motor with the shaft broke down. There was too much misalignment. When the coupling had been exchanged, the measurement test round could continue.

In figure 20 you can see the maximum movement in transversal direction and in figure 21 you can see the maximal movement with combined vertical and transverse direction. The magnification in these pictures is 25000.

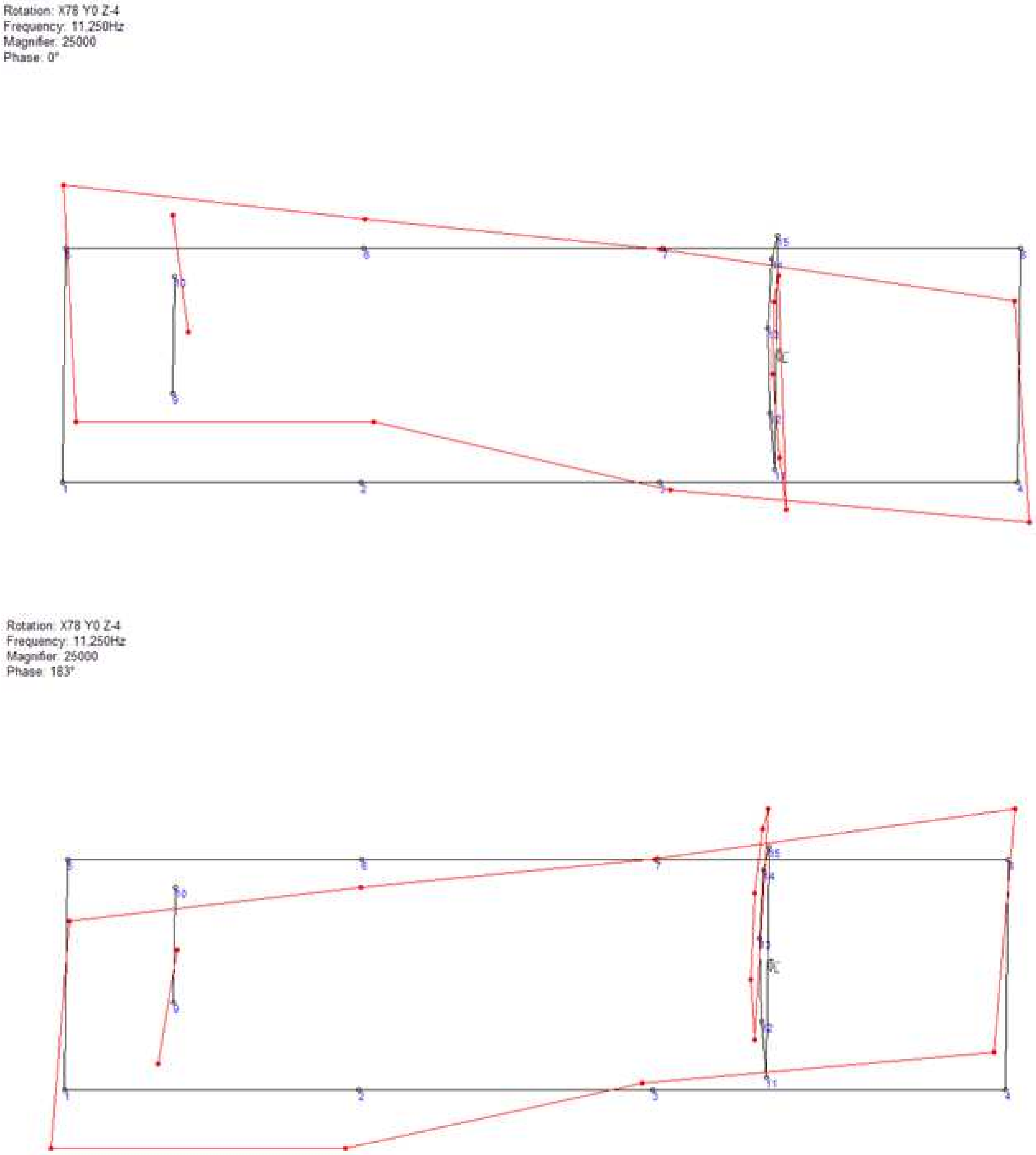


Figure 20. Mode 1: Transversal mode.

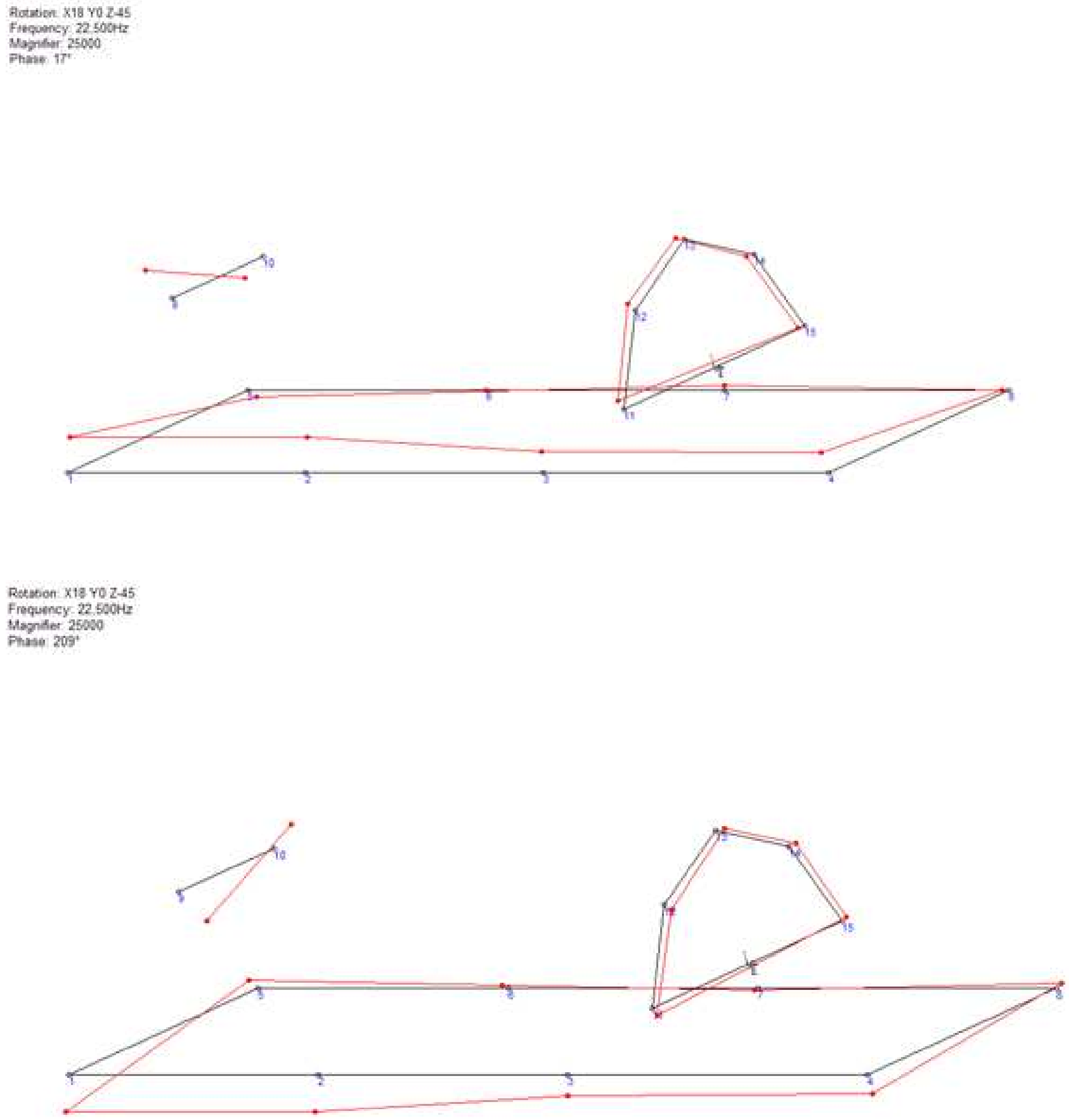


Figure 21. Mode 2: Combined vertical and transverse mode.

Figure 22 is an example of what a vibration spectrum from the mini genset looks like. The levels from the vibration spectrum measurement are at least as high as expected.

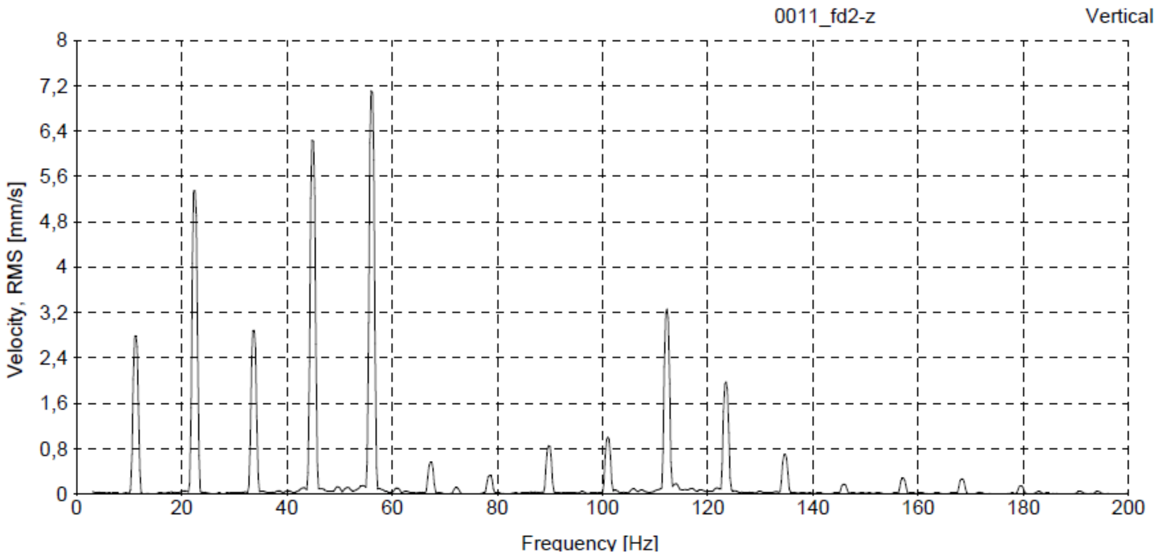


Figure 22. Vibration spectrum

No really clear natural frequency can be seen in figures 23, 24 and 25. But there is a possible natural frequency at the vertical waterfall at approximately 43 Hz. The 50 Hz peak in all three pictures is a disturbance from the electricity network.

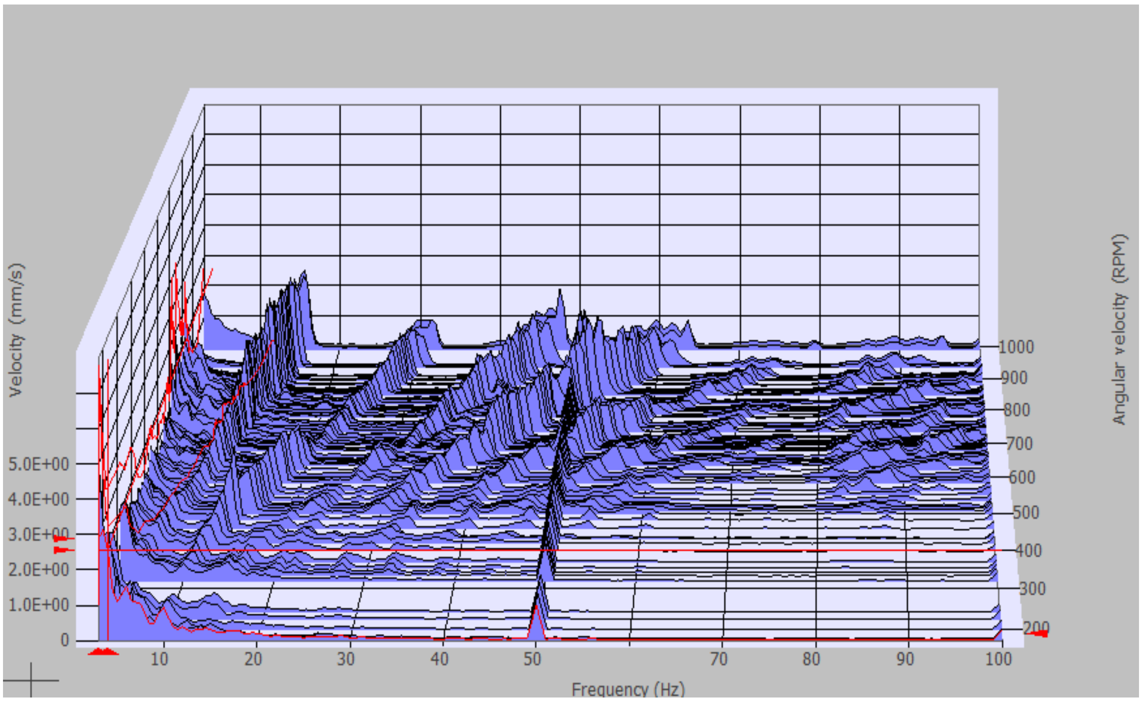


Figure 23. Waterfall spectra longitudinal

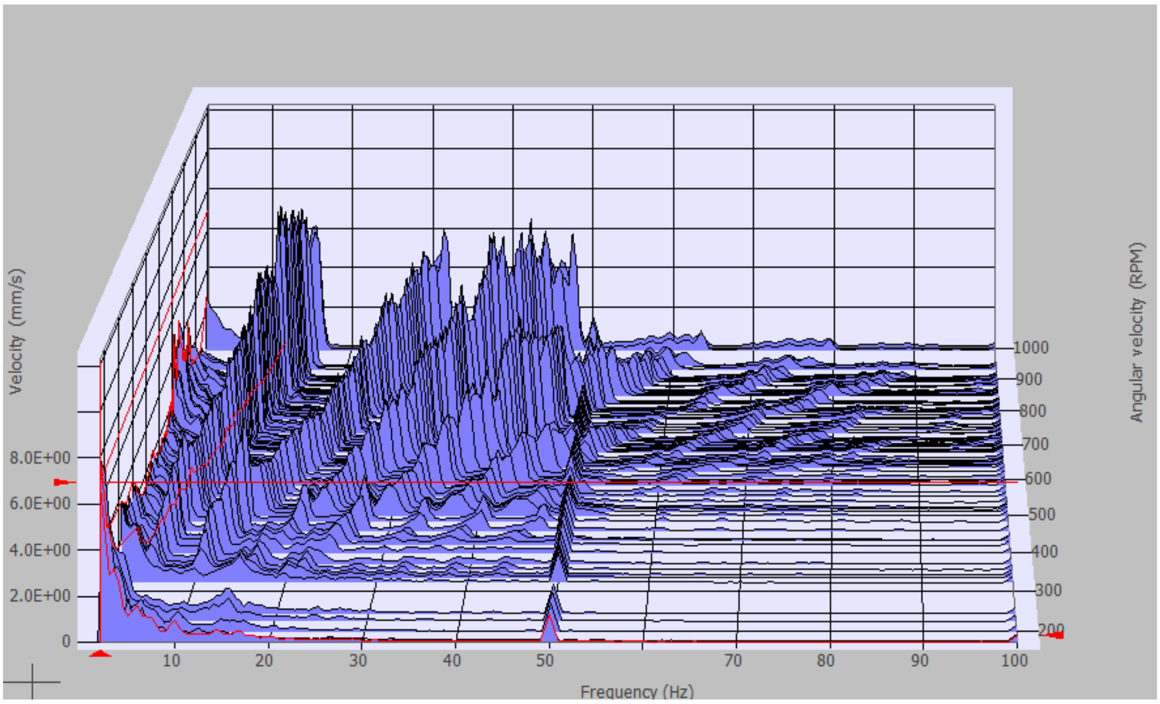


Figure 24. Waterfall spectra transversal

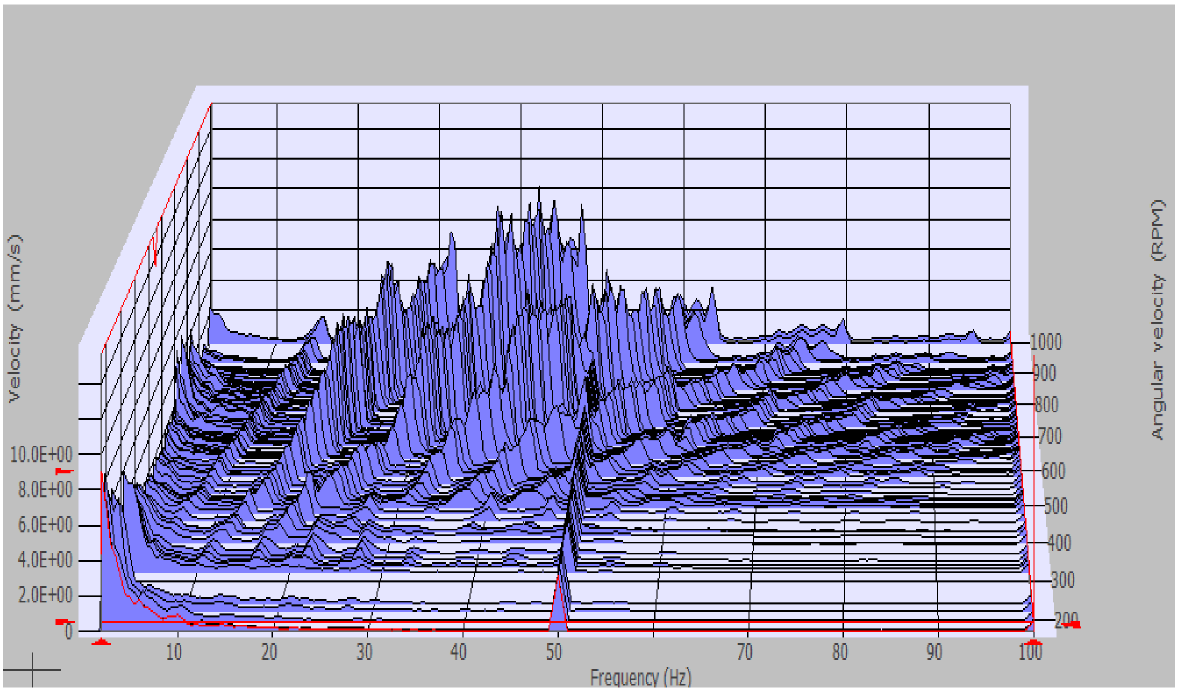


Figure 25. Waterfall spectra vertical

8 Conclusion

This Bachelor´s thesis work was interesting to do and it has been very educational. I have learned to use AutoCAD and I have learned about vibrations. It took me quite long to draw the drawings because I had not used AutoCAD much before.

There weren't any bigger problems during my work with the mini genset. One problem was that the surface of the base frame where the components were fastened was not flat. It had a small angle because of the U-profile. Some of the holes on the base frame needed to be adjusted a little. This may be the cause of the misaligned coupling that connects the trimmer motor with the shaft, which was broken. We knew about the misalignment but wanted to test how it would work and the result is that the misalignment was too big.

Things that can be made to improve the mini genset would be to make some kind of protection for hands and fingers, e.g. a hard flexible plastic around the mini genset. A possibility to change the level of the dynamic twist by changing load of the trimmer motor could also be considered. It would also be good to investigate if is possible to create a closed lubrication system for the trimmer motor. Now there is no closed lubrication system. The mini genset will also be painted in a near future.

The test run showed that there are vibrations, which is good. The levels of the vibrations were expected. This means that the mini genset will work fine as a demonstration machine and as a vibration testing machine.

I would like to thank Mr. Jari Määttä and Mr. Ulf Östman for the test measurements. I also wish to thank Mr. Peter Sundström, Mr. Pasi Kalamo and all the other people involved, including my supervisor Mr. Roger Nylund at Novia for their help to make this work possible. Finally I want to give a special thank to Mr. Matias Palmujoki for all support and help that he gave me.

Figure 26. Picture of the mini genset.

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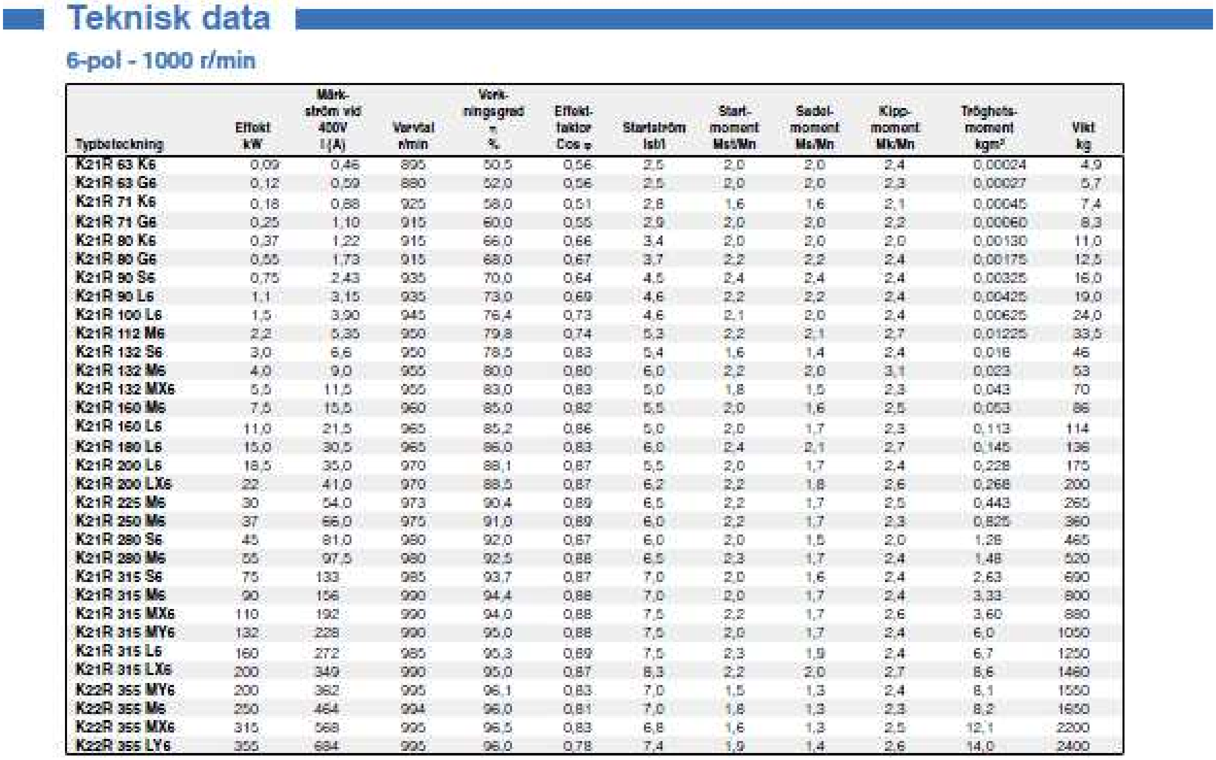
APPENDICES

Appendix 1



Teknisk data

6-pol - 1000 r/min

Typbeteckning	Effekt kW	Märk-ström vid 400V I (A)	Varvtal r/min	Verk-ningsgrad η %	Effekt-faktor Cos φ	Startström Ist/In	Start-moment Mst/Mn	Sadel-moment Ms/Mn	Kipp-moment Mk/Mn	Tröghets-moment kgm²	Vikt kg
K21R 63 K6	0,09	0,46	895	50,5	0,56	2,5	2,0	2,0	2,4	0,00024	4,9
K21R 63 G6	0,12	0,59	880	52,0	0,56	2,5	2,0	2,0	2,3	0,00027	5,7
K21R 71 K6	0,18	0,88	925	58,0	0,51	2,8	1,6	1,6	2,1	0,00045	7,4
K21R 71 G6	0,25	1,10	915	60,0	0,55	2,9	2,0	2,0	2,2	0,00060	8,3
K21R 80 K6	0,37	1,22	915	66,0	0,66	3,4	2,0	2,0	2,0	0,00130	11,0
K21R 80 G6	0,55	1,73	915	68,0	0,67	3,7	2,2	2,2	2,4	0,00175	12,5
K21R 90 S6	0,75	2,43	935	70,0	0,64	4,5	2,4	2,4	2,4	0,00325	16,0
K21R 90 L6	1,1	3,15	935	73,0	0,69	4,6	2,2	2,2	2,4	0,00425	19,0
K21R 100 L6	1,5	3,90	945	76,4	0,73	4,6	2,1	2,0	2,4	0,00625	24,0
K21R 112 M6	2,2	5,35	950	79,8	0,74	5,3	2,2	2,1	2,7	0,01225	33,5
K21R 132 S6	3,0	6,6	950	78,5	0,83	5,4	1,6	1,4	2,4	0,018	46
K21R 132 M6	4,0	9,0	955	80,0	0,80	6,0	2,2	2,0	3,1	0,023	53
K21R 132 MX6	5,5	11,5	955	83,0	0,83	5,0	1,8	1,5	2,3	0,043	70
K21R 160 M6	7,5	15,5	960	85,0	0,82	5,5	2,0	1,6	2,5	0,053	86
K21R 160 L6	11,0	21,5	965	85,2	0,86	5,0	2,0	1,7	2,3	0,113	114
K21R 180 L6	15,0	30,5	965	86,0	0,83	6,0	2,4	2,1	2,7	0,145	136
K21R 200 L6	18,5	35,0	970	88,1	0,87	5,5	2,0	1,7	2,4	0,228	175
K21R 200 LX6	22	41,0	970	88,5	0,87	6,2	2,2	1,8	2,6	0,268	200
K21R 225 M6	30	54,0	973	90,4	0,89	6,5	2,2	1,7	2,5	0,443	265
K21R 250 M6	37	66,0	975	91,0	0,89	6,0	2,2	1,7	2,3	0,825	360
K21R 280 S6	45	81,0	980	92,0	0,87	6,0	2,0	1,5	2,0	1,28	465
K21R 280 M6	55	97,5	980	92,5	0,88	6,5	2,3	1,7	2,4	1,48	520
K21R 315 S6	75	133	985	93,7	0,87	7,0	2,0	1,6	2,4	2,63	690
K21R 315 M6	90	156	990	94,4	0,88	7,0	2,0	1,7	2,4	3,33	800
K21R 315 MX6	110	192	990	94,0	0,88	7,5	2,2	1,7	2,6	3,60	880
K21R 315 MY6	132	228	990	95,0	0,88	7,5	2,0	1,7	2,4	6,0	1050
K21R 315 L6	160	272	985	95,3	0,89	7,5	2,3	1,9	2,4	6,7	1250
K21R 315 LX6	200	349	990	95,0	0,87	8,3	2,2	2,0	2,7	8,6	1460
K22R 355 MY6	200	362	995	96,1	0,83	7,0	1,5	1,3	2,4	8,1	1550
K22R 355 M6	250	464	994	96,0	0,81	7,0	1,8	1,3	2,3	8,2	1650
K22R 355 MX6	315	568	995	96,5	0,83	6,8	1,6	1,3	2,5	12,1	2200
K22R 355 LY6	355	684	995	96,0	0,78	7,4	1,9	1,4	2,6	14,0	2400

Appendix 2

Kennlinien

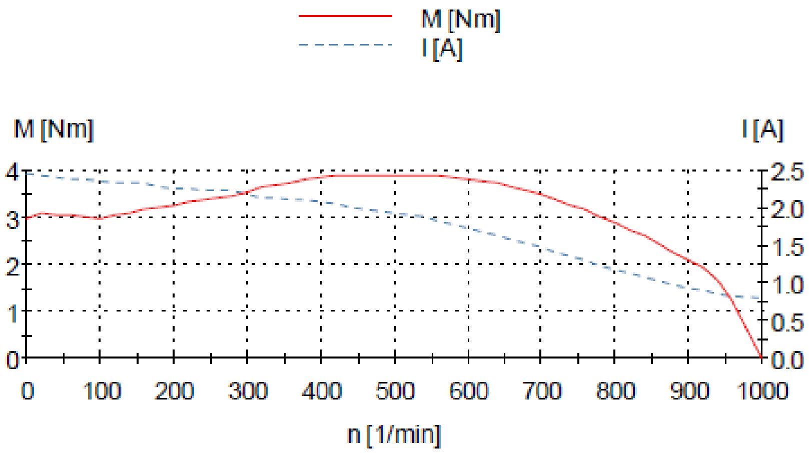
Drehstrommotoren mit Käfigläufer, Normmotoren
Graugussgehäuse

ERSTELLT MIT VEM-KATALOG, VERSION 6.5

Datum: 14.06.2011

Typ: K21R 71 K6

Kennlinien



Legende

I [A]	Strom in [A]	cos phi	Leistungsfaktor
M [Nm]	Moment in [Nm]	eta [%]	Wirkungsgrad in [%]
n [1/min]	Drehzahl in [1/min]	P1 [kW]	Aufgenommene Leistung in [kW]
P2 [%]	Abgegebene Leistung [%]	s [%]	Schlupf in [%]

Kennlinien gelten für 400 V Bemessungsspannung, 50Hz !
Dieses Dokument wurde elektronisch hergestellt, alle Angaben sind nur nach Bestätigung durch den Hersteller verbindlich.

VEM motors GmbH
Carl-Friedrich-Gauß-Straße 1
D-38855 Wernigerode
Postfach-Nr. 101252
D-38842 Wernigerode

Telefon: 0 39 43 / 68-0
Telefax: 0 39 43 / 68 21 20
E-Mail: motors@vem-group.com
Internet: www.vem-group.com

Geschäftsführer:
Jürgen Sander
Dr. Dietmar Puschkeit

Rechtsform: GmbH
Sitz: Wernigerode
Amtsgericht
Stendal HRB 112964
Ust.-Id. Nr. DE 212 649 455

Commerzbank AG Dresden
BLZ 850 400 00
Kto.-Nr. 800 15 88
SWIFT: COBA DE FF 850
IBAN: DE02 8504 0000 0800 1588 00

Deutsche Bank AG
Wernigerode
BLZ 810 700 00
Kto.-Nr. 250 04 03

CENTA
CENTAFLEX®-A

A 1.0 Performance table

Centaflex size				1	2	4	8	12	16	22	25	28	30	50	80	90	140	200	250	400	Remarks*
Pos.	Description	Symbol	Unit																		
1	Nominal Torque	T_{KN}	Nm	10	20	50	100	140	200	275	315	420	500	700	900	1100	1700	2400	3000	5000	
2	Maximum Torque	T_{Kmax}	Nm	25	60	125	280	360	560	750	875	1200	1400	2100	2100	3150	4900	6000	8750	12500	
3	Angle of Twist	T_{KN}	degree	6°	6°	5°	5°	3°	5°	3°	5°	3°	5°	3°	3°	5°	3°	3°	3°	3°	
		T_{Kmax}	degree	17°	17°	12°	14°	7.5°	14°	7.5°	14°	7.5°	14°	7.5°	7.5°	14°	7.5°	7.5°	7.5°	7.5°	
4	Max speed	n_{max}	min-1	10000	8000	7000	6500	6500	6000	6000	5000	5000	4000	4000	4000	3600	3600	3000	3000	2500	
5	Angular Elasticity	ΔK_w	degree	3°	3°	3°	3°	2°	3°	2°	3°	2°	3°	2°	2°	3°	2°	2°	2°	2°	dependant upon speed
6	Axial Elasticity	ΔK_a	mm	2	3	3	4	4	5	5	5	5	5	5	3	5	5	5	5	5	
7	Radial Elasticity	ΔK_r	mm	1.5	1.5	1.5	2	2	2	2	2	2	2	2	1.5	2	2	2	2	2	depedant upon speed
8	Cont. Oscillating Torque	T_{KW}	Nm	5	10	20	40	50	80	100	125	150	200	300	320	450	700	960	1250	2000	
9	Allowable Energy Loss	P_{KV}	W	6	10	15	25	30	40	50	68	75	80	90	100	120	150	170	200	250	
10	Dyn. Torsional Stiffness	C_{Tdyn}	Nm/rad	90	180	550	900	2700	2000	6100	2800	7500	4800	12000	16000	10500	26500	38700	43000	75000	50 Shore
		C_{Tdyn}	Nm/rad	140	290	850	1500	4400	3400	9000	4500	12000	7800	19000	25000	16000	40000	60000	67000	120000	60 Shore
11	Axial Stiffness	c_a	N/mm	38	22	75	75	250	100	500	140	550	190	650	850	220	650	900	1150	1300	
12	Radial Stiffness	c_r	N/mm	150	150	500	500	1000	500	1300	600	1400	750	2200	2900	1000	2300	3100	4100	6000	
13	Angular Stiffness	c_w	Nm/ degree	0.3	0.3	2.4	3.6	9.0	5.0	12.0	7.0	17.0	9.0	26.0	34.0	17.0	38.0	48.0	68.0	88.0	

Figures given for lines 3, 11, 12, 13 are values for a shore hardness of 60° measured statically ($c_{dyn} = C_{stat} \cdot 1{,}3$)

Nominal Torque T_{KN}:	Torque which can be transmitted throughout the entire permitted speed range.
Max. Torque T_{Kmax}:	Torque which may be applied for short periods 10^5 times, pulsating in the same direction of rotation, or 5 x 10^4 alternating.
Continuously Torque T_{KW}:	Amplitude of continuously permissable torque fluctuation at max. frequency of 10 Hz and a basic load up to nominal Torque T_{KN}.

*** Larger sizes up to 1250 Nm are available, please consult us.**

A 1.1. Starting up Factor

Z	≤ 120	120 < Z≤ 240	> 240
S_Z	1,0	1,3	1,6

Z= start frequency per hour

A 1.2. Frequency Factor

f in Hz	≤ 10	> 10
S_f	1	$\sqrt{\frac{f}{10}}$

A 1.3. Shore Hardness

Conversion Factor U				
Shore	50	60	70	75
u	0,7	1	1,6	2,3

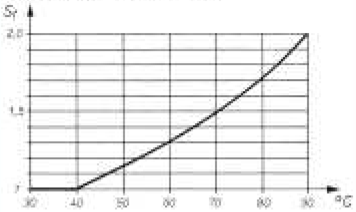
A 1.4. Surge or Pulse Factor

S_A/S_L	
1,6	Light starting load
1,9	Medium starting load
2,2	heavy starting load

A 1.5. Resonance Factor V_R Relative Damping Factor Ψ

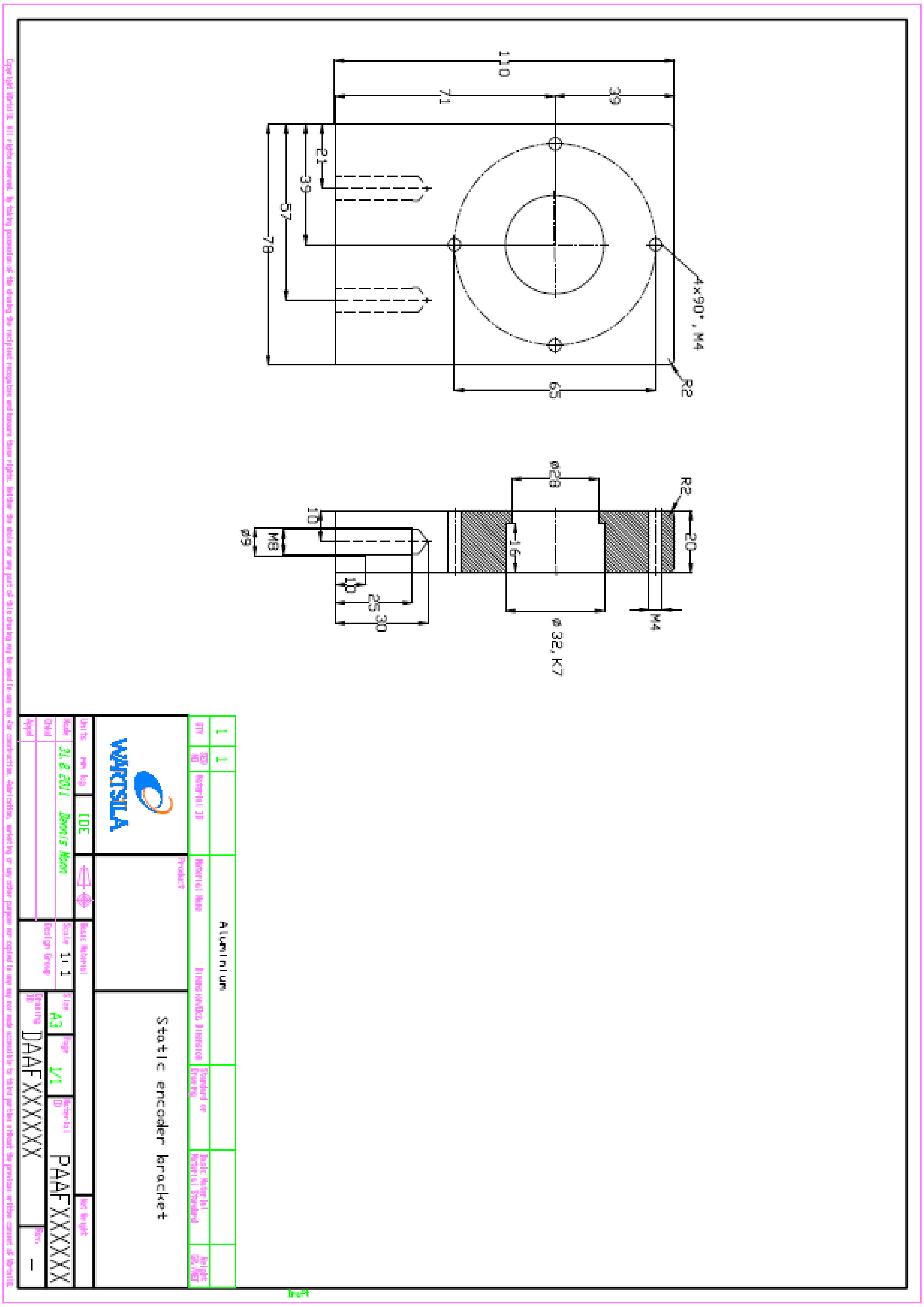
Natural Rubber (NR)		
Shore Hardn.	V_R	Ψ
50	10	0,6
60	8	0,78

A 1.6 Temperature factor

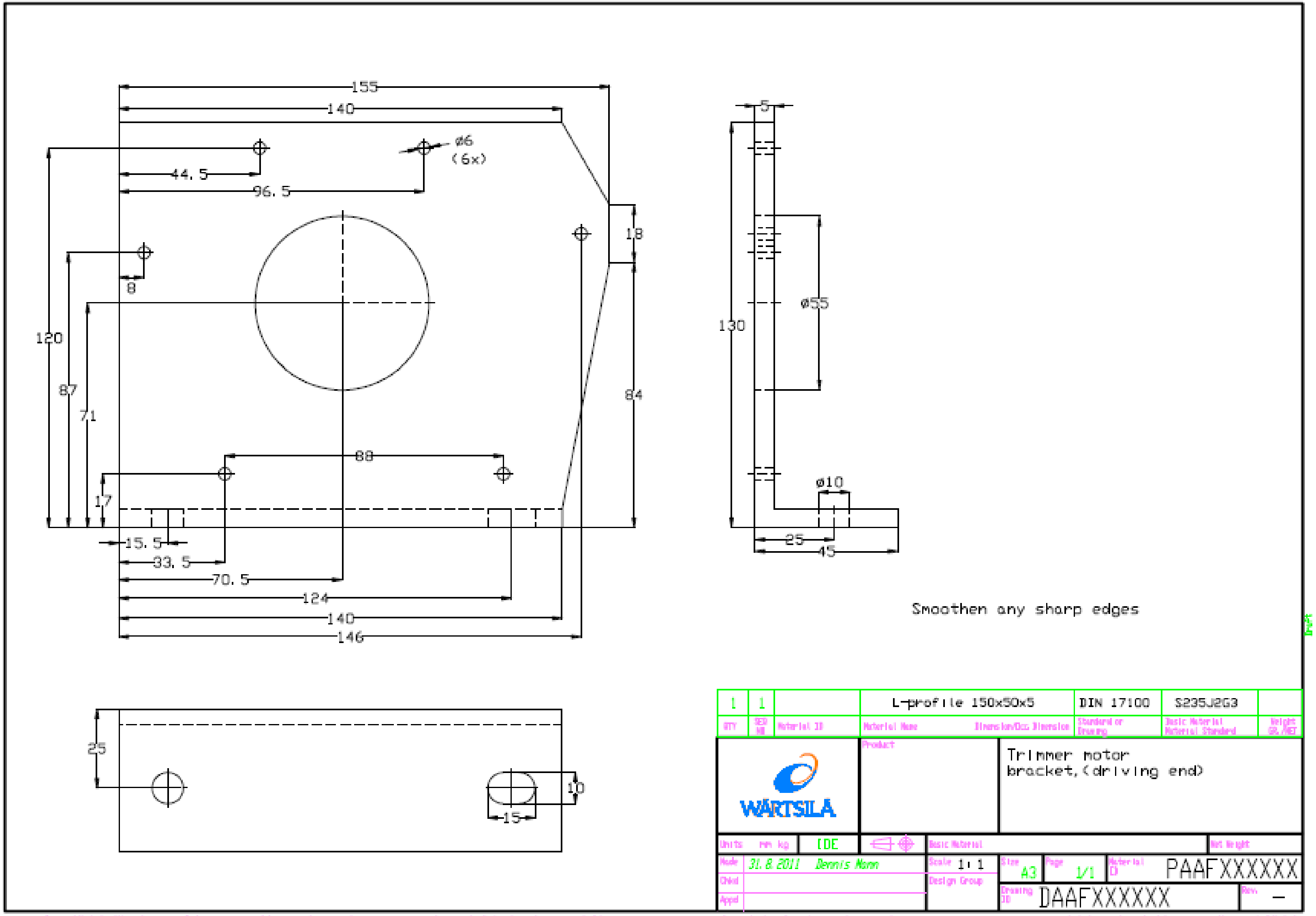


A 1.7 Permissible angular and radial misalignment

permissible angular and parallel offset misalignment is dependant upon the speed when utilising the nominal torque capacity. % of line 5 or 7


110
71
39
21
39
57
78
4×90°, M4
R2
65
ø28
R2
10
ø9
M8
16
20
10
25
30
ø32, K7
M4
QTY 1
SEQ NO 1
Material ID
Material Name
Aluminium
Dimension/Doc. Dimension
Standard or Drawing
Basic Material Material Standard
Weight
Product
Static encoder bracket
Units mm kg
CDE
Basic Material
Scale 1:1
Made 31.8.2011 Dennis Moon
Chkd
Appd
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Net Weight
Drawing ID DAAFXXXXXX
Rev. -
WÄRTSILÄ

Appendix 5



Smoothen any sharp edges

QTY	SEQ NR	Material ID	Material Name / Dimension/Occ. Dimension	Standard or Drawing	Basic Material Material Standard	Weight GR./NET
1	1		L-profile 150x50x5	DIN 17100	S235J2G3	

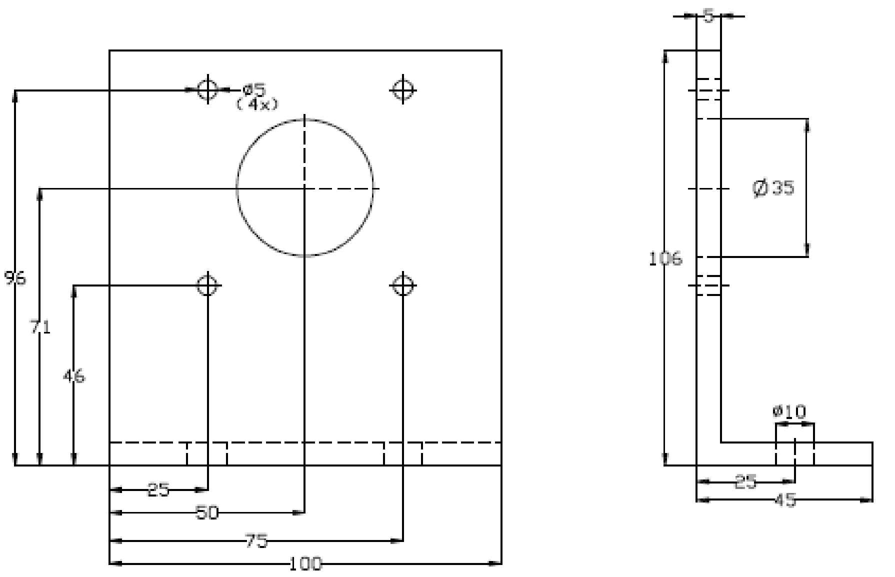
Product

Trimmer motor
bracket,(driving end)

Units mm kg
IDE
Basic Material
Net Weight
Made 31.8.2011 Dennis Mann
Chkd
Appd
Scale 1:1
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Drawing ID DAAFXXXXXX
Rev. –

Draft

Appendix 6



Smoothen any sharp edges

QTY	SEQ NO	Material ID	Material Name / Dimension/Occ Dimension	Standard or Drawing	Basic Material Material Standard	Weight GR./NET
1	1		L-profile 125x65x5	DIN 17100	S235J2G3	

WÄRTSILÄ

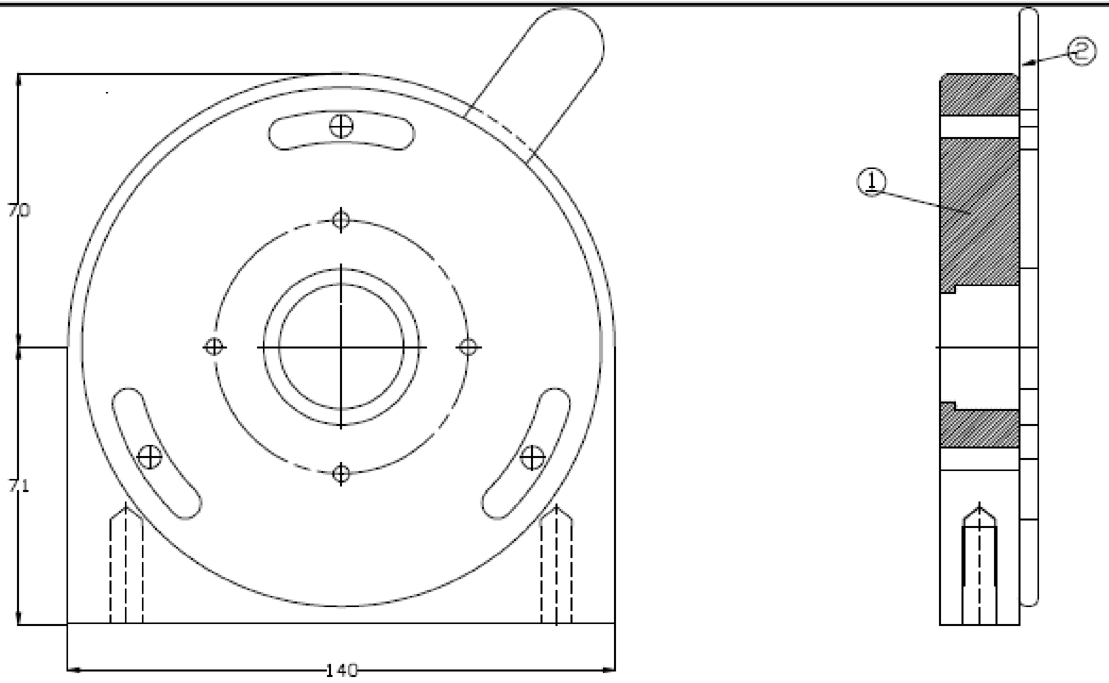
Product

Trimmer motor
bracket,(PTO end)

Units mm kg	IDE	Basic Material		Net Weight
Made 31.8.2011 Dennis Monn	Scale 1:1	Size A3	Page 1/1	Material ID PAAFXXXXXX
Chkd	Design Group	Drawing ID DAAFXXXXXX		Rev. –
Appd				

Draft

Appendix 7



QTY	SEQ NO	Material ID	Material Name Dimension/Occ Dimension	Standard or Drawing	Basic Material Material Standard	Weight GR./NET
1	1		Adjustable encoder bracket, part 1			
1	2		Adjustable encoder bracket, part 2			

WÄRTSILA

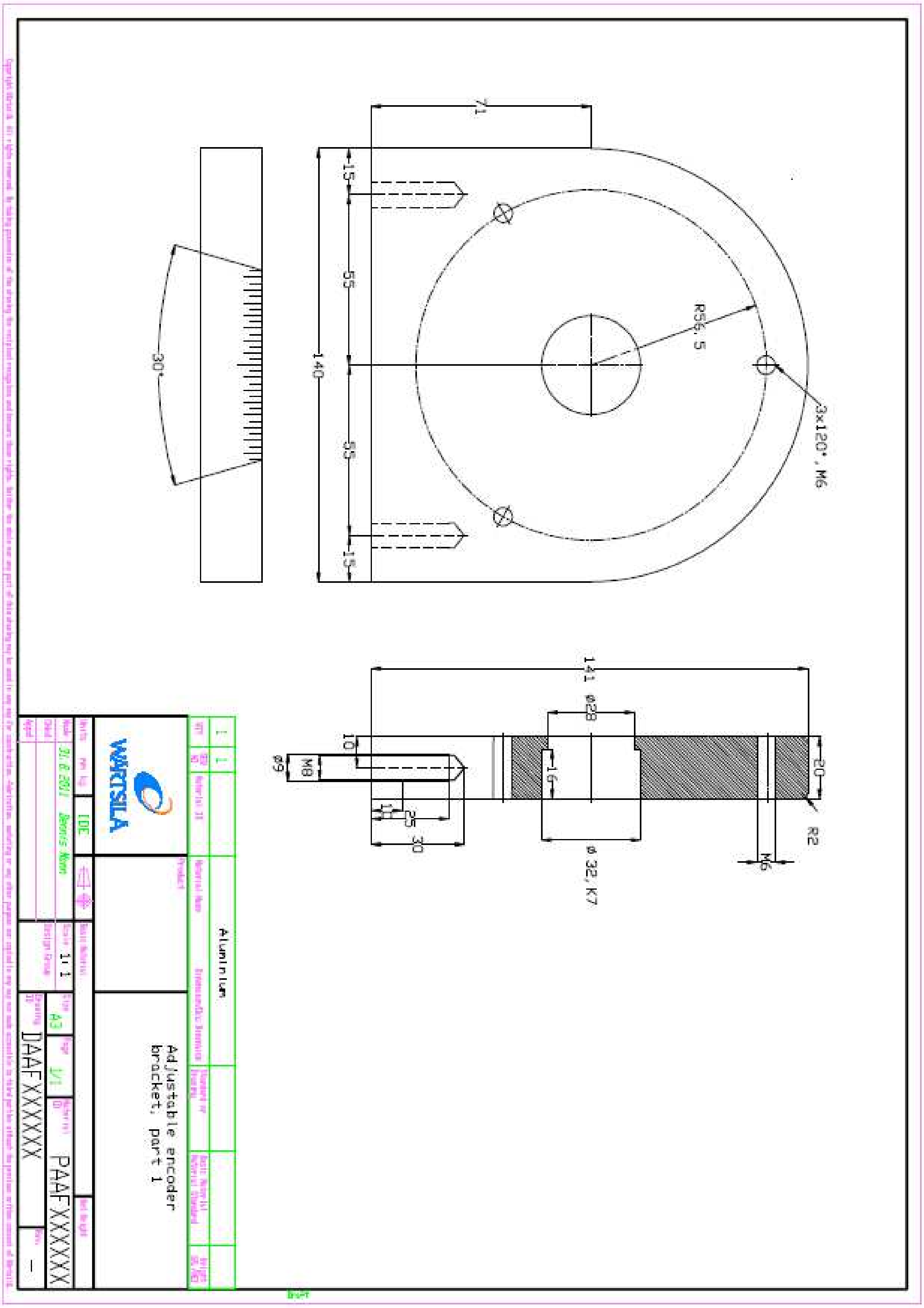
Product

Adjustable encoder bracket

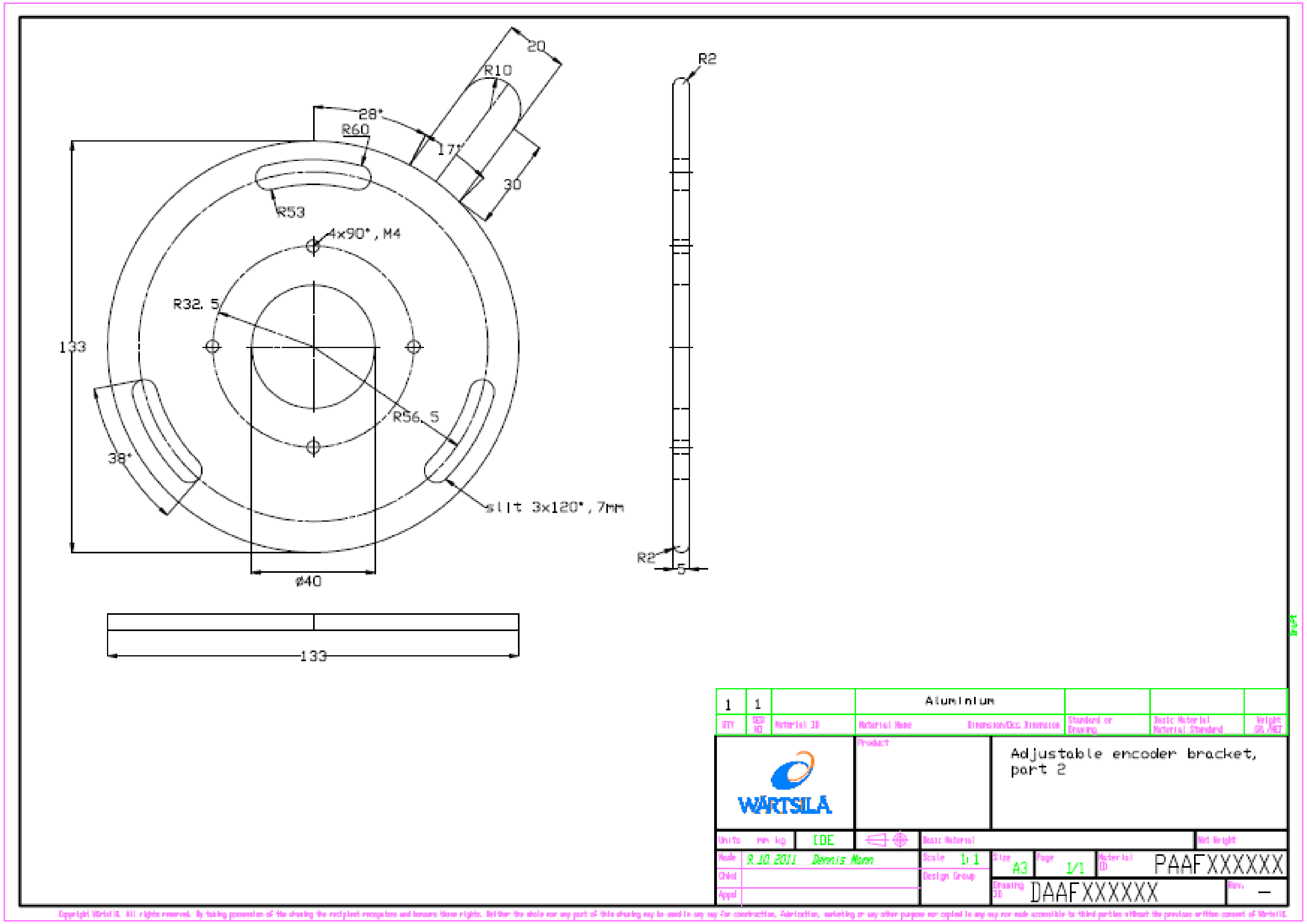
Units mm kg
IDE
Basic Material
Net Weight
Made 31. 8. 2011 Dennis Mann
Chkd
Appd
Scale 1: 1
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Drawing ID DAAFXXXXXX
Rev. –

Draft

Appendix 8


71
15
55
140
55
15
30°
R56.5
3x120°, M6
141
ø28
10
20
M8
ø9
16
11
25
30
R2
M6
ø 32, K7
1
1
WÄRTSILÄ
IDE
31.8.2017
Dennis Mann
Aluminium
1:1
A3
1/1
Adjustable encoder bracket, part 1
DAAFXXXXXX
PAAFXXXXXX
–

Appendix 9


133
133
ø40
R32.5
R53
R56.5
R60
R10
R2
R2
5
4×90°, M4
slit 3×120°, 7mm
28°
38°
17°
30
20
1
1
Aluminium
QTY
SER NO
Material ID
Material Name
Dimension/Occ Dimension
Standard or Drawing
Basic Material Material Standard
Weight GR./NET
Product
Adjustable encoder bracket, part 2
WÄRTSILÄ
Units mm kg
IDE
Basic Material
Net Weight
Made 9.10.2011 Dennis Mann
Chkd
Appd
Scale 1:1
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Drawing ID DAAFXXXXXX
Rev. –
Draft
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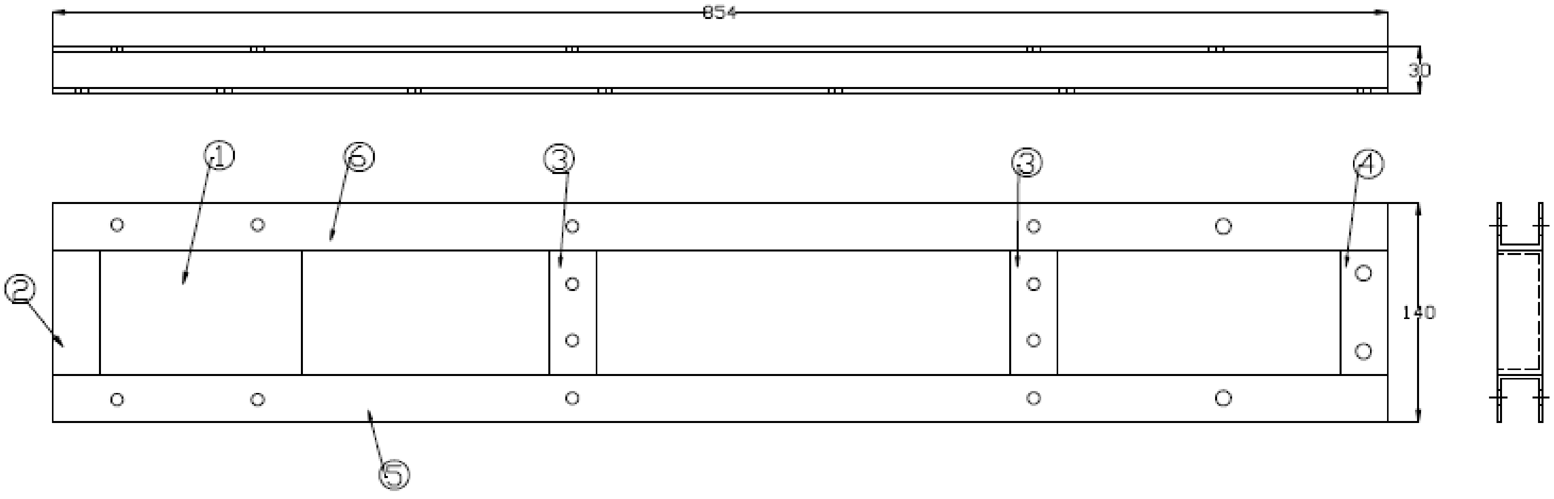


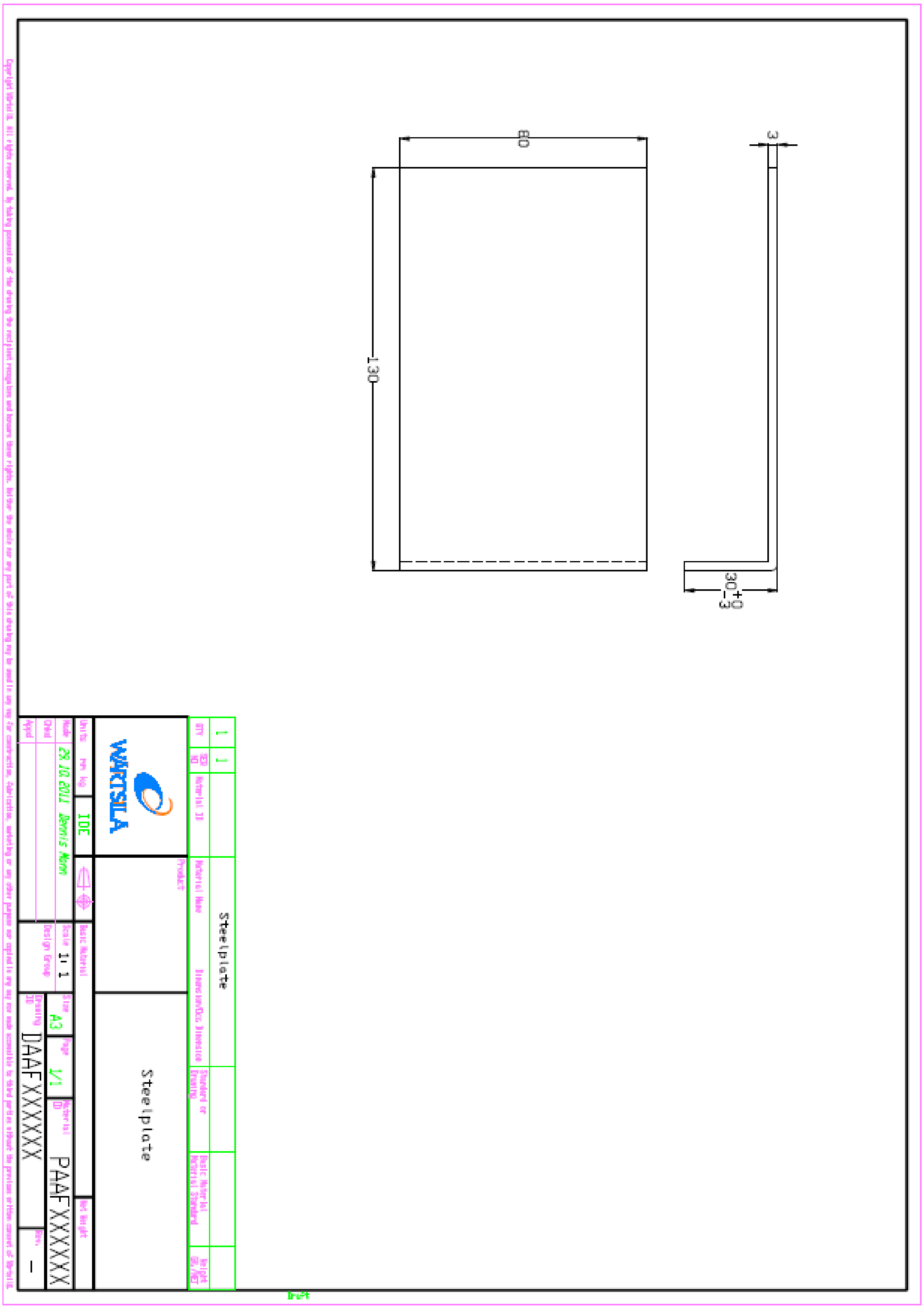
1	1		Steelplate			
1	2		U-bracket			
2	3		Middle bracket			
1	4		End bracket			
1	5		Right bracket			
1	6		Left bracket			
QTY	SER NO	Material ID	Material Name Dimension/Occ Dimension	Standard or Drawing	Basic Material Material Standard	Weight GR./NET

Product

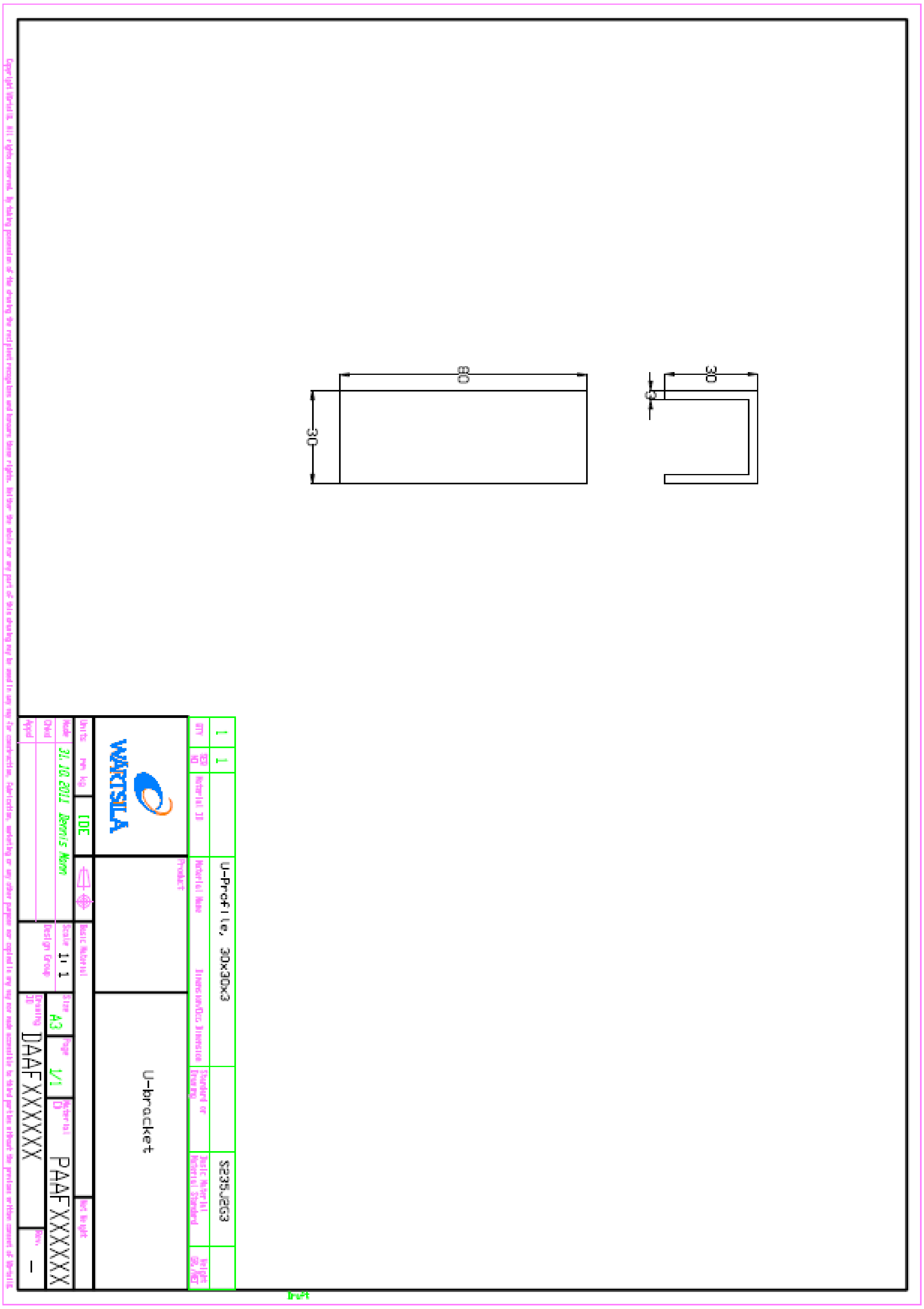
Baseframe

Units: mm kg
IDE
Basic Material
Net Weight
Made 31. 10. 2011 Dennis Mann
Chkd
Appd
Scale
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Drawing ID DAAFXXXXXX
Rev. –

Appendix 11


80
130
3
30+0 -3
QTY 1
SEQ NO 1
Material ID
Material Name
Dimension/Occ. Dimension
Standard or Drawing
Basic Material Material Standard
Weight (Gr./NET)
Steelplate
Product
Steelplate
WÄRTSILÄ
Units mm kg
IDE
Made 29 JUL 2011 Dennis Maron
Chkd
Appd
Basic Material
Scale 1:1
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Net Weight
Drawing ID DAAFXXXXXX
Rev. -
Draft

Appendix 12


80
30
30
3
QTY 1
ITEM NO 1
Material ID
Material Name U-Profile, 30x30x3
Dimension/Desc. Dimension
Standard or Drawing
Basic Material Standard S235JRG3
Weight (kg, NET)
WÄRTSILÄ
Product
U-bracket
Units mm kg
IDE
Basic Material
Net Weight
Made 31.10.2011 Dennis Akom
Chkd
Appd
Scale 1:1
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Drawing ID DAAFXXXXXX
Rev. –
Draft
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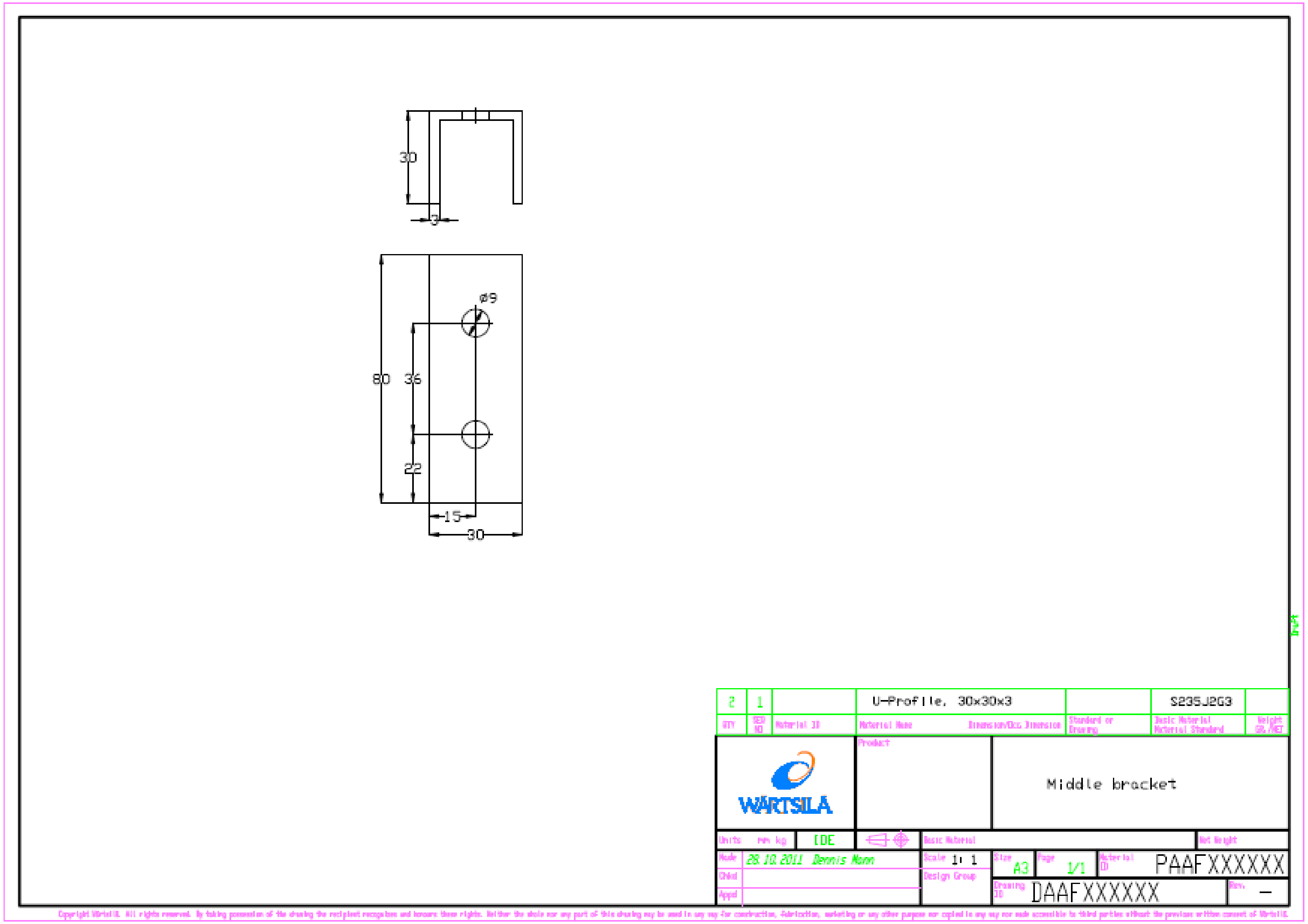
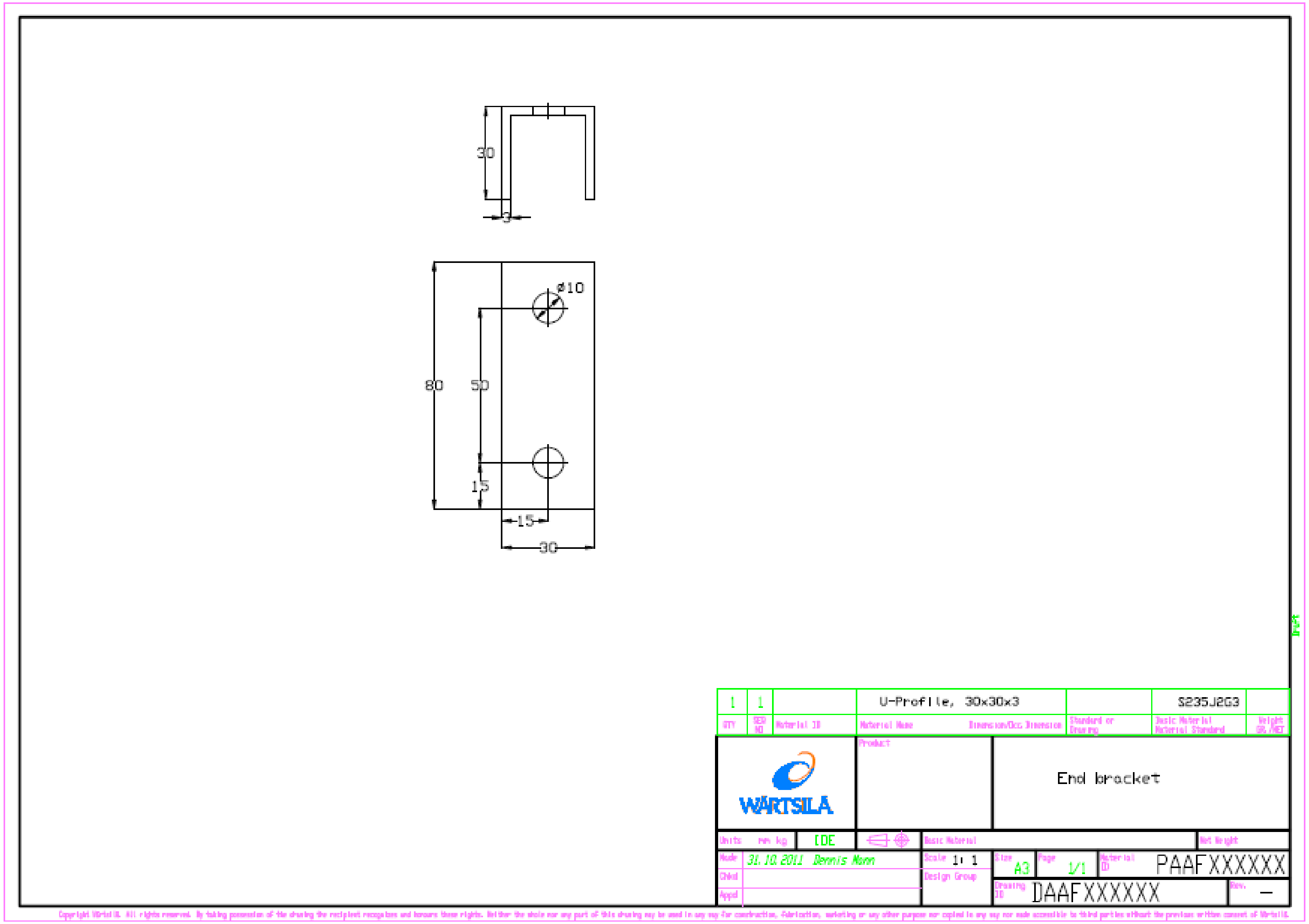
Appendix 13


30
3
ø9
80
36
22
15
30
2
1
U-Profile, 30x30x3
S235J2G3
QTY
SEQ NO
Material ID
Material Name
Dimension/Occ. Dimension
Standard or Drawing
Basic Material Material Standard
Weight GR./NET
WÄRTSILÄ
Product
Middle bracket
Units mm kg
IDE
Basic Material
Net Weight
Made 28.10.2011 Dennis Mann
Chkd
Appd
Scale 1:1
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Drawing ID DAAFXXXXXX
Rev. –
Draft


30
3
ø10
80
50
15
15
30
1
1
U-Profile, 30x30x3
S235J2G3
QTY
SEQ NO
Material ID
Material Name
Dimension/Occ Dimension
Standard or Drawing
Basic Material Material Standard
Weight SG./NET
Product
End bracket
WÄRTSILÄ
Units mm kg
IDE
Basic Material
Net Weight
Made 31.10.2011 Dennis Mann
Chkd
Appd
Scale 1:1
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Drawing ID DAAFXXXXXX
Rev. –
Draft
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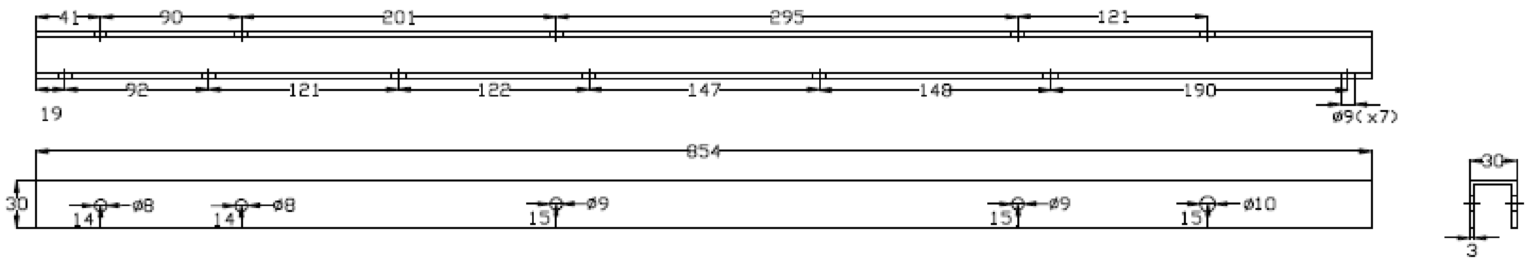
Appendix 15



QTY	SER NO	Material ID	Material Name	Dimension/Dcc Dimension	Standard or Drawing	Basic Material Material Standard	Weight GR./NET
1	1		U-Profile, 30x30x3			S235J2G3	

WÄRTSILÄ

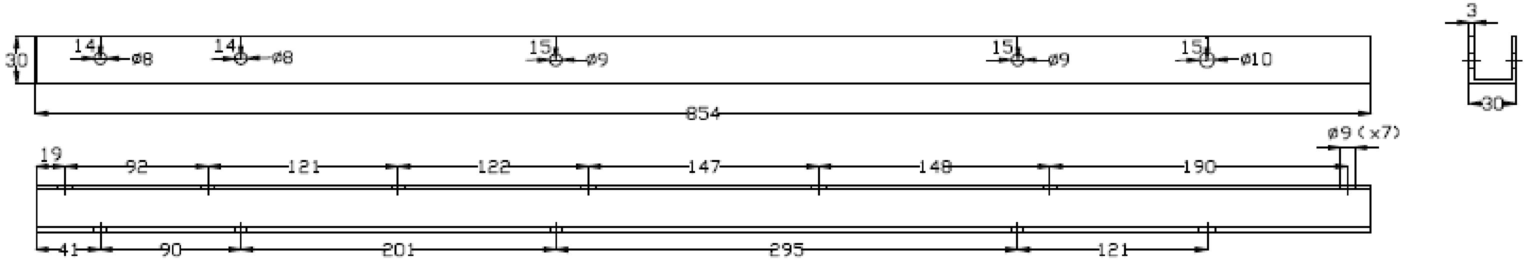
Product

Right bracket

Units: mm kg
IDE
Basic Material
Net Weight
Made 31.10.2011 Dennis Mann
Chkd
Appd
Scale
Design Group
Size A3
Page 1/1
Material ID PAAFXXXXXX
Drawing ID DAAFXXXXXX
Rev. –

Draft

Appendix 16



1	1		U-Profile, 30x30x3		S235J2G3	
QTY	SER NO	Material ID	Material Name Dimension/Occ Dimension	Standard or Drawing	Basic Material Material Standard	Weight GR./NET

Product

Left bracket

Units mm kg

IDE

Basic Material

Net Weight

Made 31. 10. 2011 Dennis Mann

Chkd

Appd

Scale

Design Group

Size A3

Page 1/1

Material ID PAAFXXXXXX

Drawing ID DAAFXXXXXX

Rev. –

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