Equipping of Deep-Drawing Press with Force Measurement

HAMK
UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Mechanical Engineering and Production Technology

Riihimäki 03.12.2011

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BACHELOR'S THESIS

Mechanical Engineering and Production Technology
Riihimäki

Title	Equipping of deep-drawing press with force measurement
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Approved on	15.12.2011
Approved by	Lassi Martikainen

HAMK
UNIVERSITY OF APPLIED SCIENCES

ABSTRACT

Riihimäki
Mechanical Engineering and Production Technology
Mechatronics

Author Kimi Jukka Nissinen **Year** 2011

Subject of Bachelor's thesis Equipping of Deep-Drawing Press with Force Measurement

ABSTRACT

The aim of the thesis is to design, execute and test the equipping of sheet metal deep-drawing press with force measurement system for materials research purposes. The topic of this thesis was commissioned by the Sheet Metal Centre of HAMK University of Applied Sciences in Hämeenlinna, Finland. The results gained from this thesis will develop the research and educational environment and services of the Sheet Metal Centre.

After becoming familiar with the deep-drawing of sheet metal, the different measuring techniques were studied in order to select the most suitable equipment for the case based on selection criteria such as the measuring capability, specifications, availability, and costs. The structure of the press was modified and new parts were designed for the transducer installation. Finally, load cells were utilized to measure the forces of the hydraulic cylinders in the press and linear variable differential transformers to measure the displacement of the cylinders. The data was directly transferred and formulated in PC measuring software to provide information about the behavior of the work piece material during the deep drawing operation.

The new structure of the press with transducers was designed with aspect on the required performance of the device in relation what is applicable and possible to achieve without compromising the ease of assembly, structural soundness, measuring accuracy and costs. The end result is a versatile measuring system that provides reliable results yet provides possibilities for further additions and connectivity to other analysis devices.

Keywords sheet metal, deep drawing, force measurement, load cell

Pages 29 p. + appendices 13 p.

HÄMEEN AMMATTIKORKEAKOULU

Riihimäki
Mechanical Engineering and Production Technology
Mechatronics

Tekijä	Kimi Jukka Nissinen	**Vuosi** 2011
Työn nimi	Syvävetopuristimen varustaminen voimanmittauksella	

TIIVISTELMÄ

Tämän opinnäytetyön tarkoituksena oli suunnitella, toteuttaa ja testata ohutlevyn syvävetoon käytettävään puristimeen voimanmittausjärjestelmä. Tehtävänantaja oli Hämeen ammattikorkeakoulun Ohutlevykeskus Hämeenlinnassa. Opinnäytetyön tuloksia käytetään Ohutlevykeskuksen tutkimus- ja opetusympäristön sekä -palveluiden kehittämisessä.

Ohutlevyn muovaamiseen syvävetotekniikalla perehtymisen jälkeen erilaisia mittaustekniikoita vertailtiin sopivimman laitteiston valitsemiseksi. Vertailuperusteina käytettiin muunmuassa laitteiden mittauskykyä, ominaisuuksia, saatavuutta ja kustannuksia. Puristimen rakennetta muutettiin ja uusia osia suunniteltiin antureiden asentamiseksi. Lopulta päädyttiin käyttämään erillisiä voima-antureita voimanmittaukseen puristimen hydraulisylintereissä ja induktiivisia siirtymäantureita sylintereiden liikkeen mittaukseen. Mittauslukemat siirretään suoraan käsiteltäväksi PC-mittausohjelmassa jossa niitä voidaan edelleen käsitellä haluttuun muotoon.

Puristimen uusi rakenne on suunniteltu täyttämään laitteen suorituskykyvaatimukset. Eri toteutusmahdollisuuksia määrittivät rakenteen ja laitteiston asennettavuus, kestävyys ja mittaustarkkuuden varmistaminen. Myös kustannukset oli minimoitava. Työn lopputulos on joustava mittausjärjestelmä, joka tuottaa luotettavaa tietoa ja on liitettävissä moniin muihin tutkimusvälineisiin.

Avainsanat ohutlevy, syväveto, mittaus, voima, anturi

Sivut 29 s. + liitteet 13 s.

CONTENTS

1 INTRODUCTION

The topic of this thesis is the equipping of a hydraulic deep-drawing press with force measurement equipment and displacement transducers for materials research purpose. The topic was provided by the Sheet Metal Centre (SMC) of HAMK University of Applied Sciences in Hämeenlinna, Finland, which provides material testing services for sheet metal industry. The purpose of the thesis is to study how the forces involved in the process can be measured in order to gain numerical information for the analysis of different forming process tests, and then apply the knowledge in designing a measurement system for the target device. The outcome of the work is the equipping of the hydraulic 200/100 ton press in use at the SMC with a force-displacement measuring system, helping the staff to offer better services for their clients. Reasons for choosing this topic are the combination of mechanical and electronic aspects involved in designing the system that require studying both the mechanics of deep-drawing and measurement technology in order to generate accurate and relevant end results.

2 DEEP-DRAWING TECHNOLOGY

The deep drawing operation is essentially simple. However, multiple issues arise during the forming of the work piece. The change of shape introduces various strains into the material that are complex in direction and magnitude. Deep drawing causes a permanent deformation of the material meaning that the yield strength is always exceeded. For the operation to be successful and able to produce accurate, structurally sound parts, both the material and process must meet conditions discussed in the next chapters.

2.1 Overview as manufacturing process

The manufacturing process where flat material, usually sheet metal, is forced down through an opening into a three-dimensional shape by punching is called drawing. When the depth of draw is less than its diameter, or the smallest dimension across the drawn section, the process is called shallow drawing. When the depth exceeds these dimensions, the process is called deep drawing. Deep-drawing is commonly a cold-forming manufacturing process (Black, Kohser 2008, 440).

The process is capable of producing final work pieces that generate little scrap material with enough precision for the parts to be straight assembled without further operations. Deep drawing is widely used in the manufacturing industry also because of its rapid cycle times, e.g. up to 3000 items per hour (Philip, Bolton 2002, 327). Complex geometries, not necessarily axisymmetrical, can be produced with a few operations which are automatable and thus require a relatively non-technical workforce. Deep drawing has been developed at a fast rate, especially in the automotive and aircraft industries. Typical products are cylindrical, conical or box-shaped parts such as containers, sinks, cans, pans and panels. The raw material for it is required to be ductile for the manufacturing process but tough and strong for the products to be of practical use. Generally the deep drawing operation can be combined with other manufacturing operations such as shearing and punching. A process press, using the different operations simultaneously, can rapidly produce complex parts needing no further attention. (Boljanovic 2004, 69-70)

2.2 Drawing process

Deep drawing involves the forming of a flat sheet of material, blank, into a shell by means of forcing it through an aperture in the die (Fig 1). The force is exerted by the punch that is mechanically or hydraulically operated and protruded through the die. As the punch protrudes and material is pulled inward, the diameter of the blank reduces. The blank flows between the blank holder and die towards the die cavity to form a wall and bottom. Volume of material must remain constant during the operation, resulting in the flow of material into a three-dimensional shape where previously flat material has formed the bottom and walls. Usually in deep drawing operations the thickness of material is desired to be kept constant at all locations of the part.

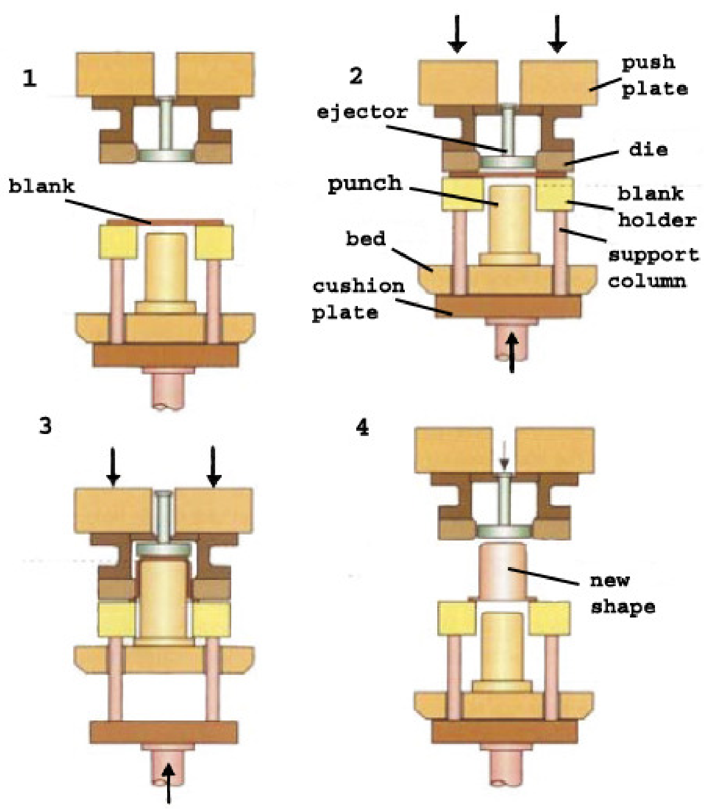

Figure 1 Stages of deep-drawing procedure (Schuler GmbH 1998, 563)

The flow is controlled by the blank holder that holds down the sheet at a certain force. If no blank holding was present, the circumferential compressive stress caused by the material flowing into the die would be released by buckling or wrinkling of the sheet (Black, Kohser 2008, 440).

The characteristics of the deep-drawing process have a significant effect on what kinds of shapes are producible and what materials can be used successively. The limiting draw ratio depicts the ratio of blank diameter to punch diameter. The wall height achieved with a single draw is limited by the maximum draw ratio. Usually draw ratios are less than 2.2 (Black, Kohser 2000, 440). Wrinkling is a major defect in deep-drawn parts and can directly be affected through the control of the blank holder force. Tool shape and features such as the die corner radius and the punch corner radius, as well as surface roughness affect the friction at the flow surfaces and therefore have an impact on the product quality. Lubrication is used to lower the coefficient of friction during the process. Through the use of draw beads, i.e. vertical projections and matching grooves on the tool, different regions of the draw can be constrained in their flow rate into the die.

2.3 Material

The raw material used for deep-drawing is generally a ductile metal that is easily formed, such as low-carbon steel (Philip, Bolton 2002, 327), but basically can be anything that deforms plastically at a wide range of deformation before failing. “A low-yield, high-tensile, and high-uniform elongation all combine to indicate a large amount of useful plasticity” (Black, Kohser 2008, 449). The success of the drawing operation is strongly dependant of the material properties. With unsuitable materials, cracks and tears are formed in the product even when the process variables, such as the draw ratio, have been set to the minimum suitable levels.

Sheet metal in its flat form has already been worked on by various processes, such as casting, hot rolling and cold rolling. Each stage changes the microstructure of the material and gives it particular properties. Concepts such as strain hardening and anisotropy of the material are discussed when selecting the suitable material for drawing operations (Boljanovic 2004, 70). Sheet metal has often rather differing characteristics with direction which due to strain hardening caused by cold rolling. As mentioned above, usually deep-drawn products should have a constant thickness. Thinning occurs when the material elongates, meaning that not all of the radius of the blank forms walls for the three-dimensional shape. (Black, Kohser 2008, 449).

2.4 Research

As with all types of manufacturing processes, the mechanical properties of the material are of interest as they measure how a particular material is applicable to a certain process; how it behaves when deformed into the desired shape. Strength, hardness, toughness, elasticity, plasticity, brittleness, ductility, are measures of this behavior for sheet metal as well, depicted in terms of the types of strains that the metal withstands and in which relation are they to stress. In order to define how a particular material is applicable to forming by deep drawing and how it compares with other materials, the strain states within the work piece during and after the process should be determined.

The analysis of material's behavior in the deep-drawing process at the Sheet Metal Centre is currently carried out by performing a draw operation for a specimen of a particular material and examining its form after the process. A grid etched into the surface of the specimen (Fig. 2) provides reference points for the examination work, where e.g. the anisotropy of the material (directional dependability) can be extracted by pointing out where and in which direction cracks and tears are formed. Theoretical strains in the sheet metal during the draw operation could then be calculated through the knowledge of advanced mechanics of materials, or by using optical measurement systems such as the GOM ARAMIS.

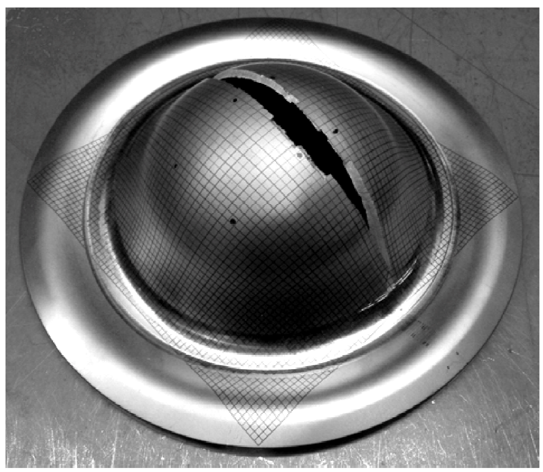

Figure 2 Tested specimen with an etched grid for analyzing its surface strains

2.4.1 Strain state

The work piece in deep-drawing is subjected to various types of stress during the forming, resulting in strain into various directions. The study of the strain state is a key element in determining characteristics of materials for forming.

The greatest deformation occurs in the flange region of the part, while the bottom part of the drawn shape remains in a relatively unstrained state. This is due to the forming load being transferred from the punch radius through the drawn part wall into the flange. The resulting tensile radial and compressive tangential stresses (hoop stresses) lead to buckling of the sheet and wrinkling of the flange, as discussed in chapter 2.2, if no blank holder force is present (Mukherjee 2011, 177). During the plastic deformation, the theoretical overall stress eventually remains close to constant while the strain increases (growth of wall area). Because the volume of material remains constant, the thickness of the wall is reduced, subsequently limiting the possible depth of draw. This is the basis of the limiting draw ratio, discussed in chapter 2.2.

The decrease in sheet metal cross-sectional area introduces the concept of true stress – true strain, which gives a better indication of the material state during forming than the nominal stress or strain. A regular engineering stress – strain curve shows the amount of stress required for increase in strain to drop after the "necking" point. This is due to the work piece cross-sectional area reducing after the material's ultimate tensile strength is exceeded. Overall true stress during the draw continues to increase the whole way up to the fracture point (Boljanovic 2004, 19). The instantaneous cross-sectional area of the strained material during the forming is obviously practically impossible to be determined. Therefore even the accurate theoretical evaluation of stresses in the sheet metal is difficult.

2.4.2 Device

The deep-drawing press at the SMC is Stenhøj 200/100 (Fig 3). It is used in materials research, to study formability of material. The press is single-action and equipped with two hydraulic cylinders, an upper with 200 tons of press force capability and a lower with 100 tons capability. The deep drawing tools (Fig. 4) are generally situated between the hydraulic cylinders.

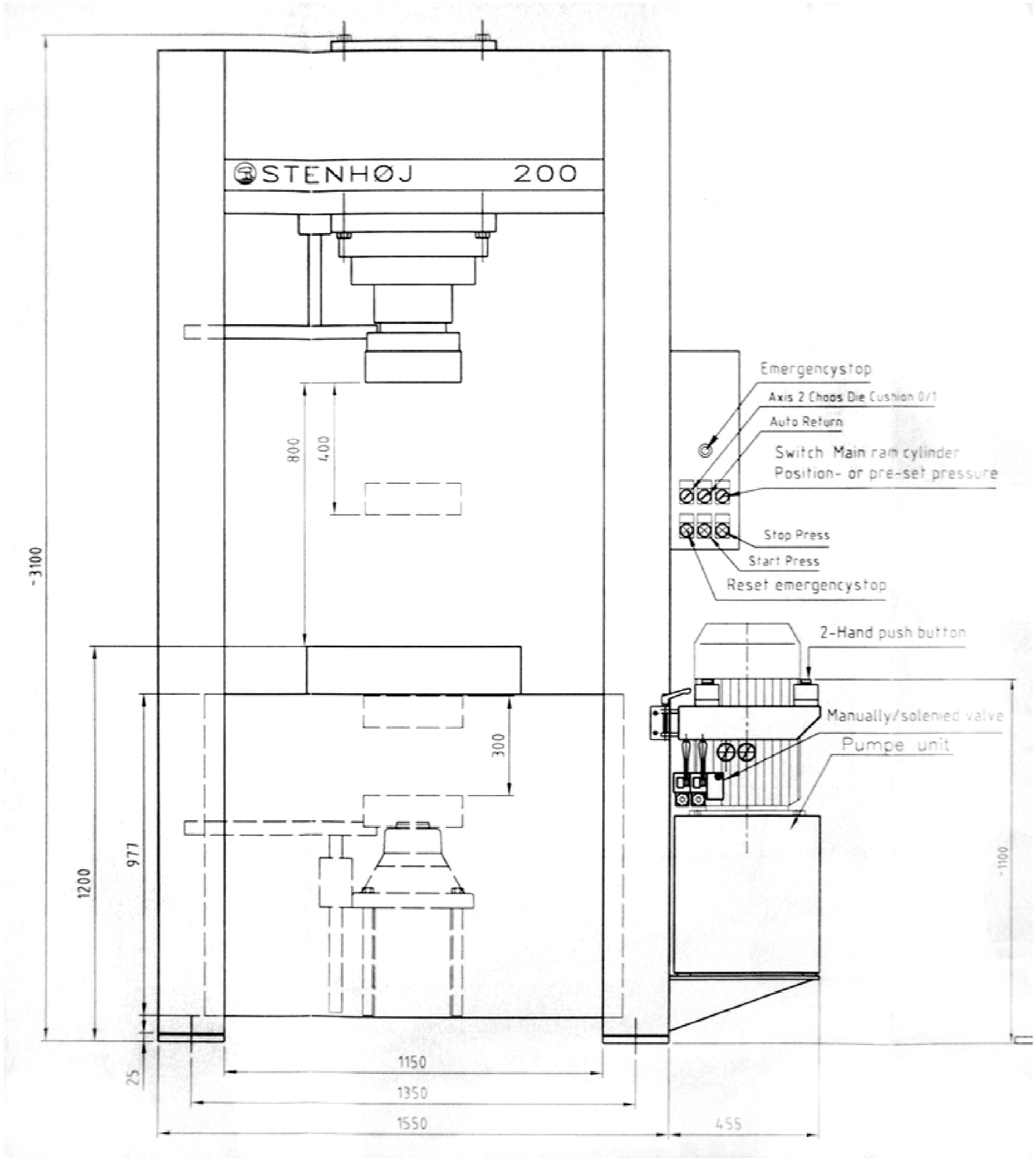

Figure 3 Stenhøj 200/100 press at SMC (Stenhøj 2007, 2)

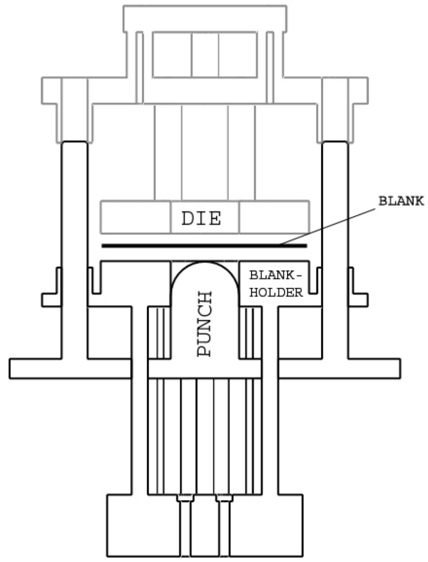

Figure 4 Outlay of the press tool

The blank holder is in connection to the lower hydraulic cylinder which acts as suspension. The die is actuated using the upper hydraulic cylinder which acts as ram. The punch is stationary and mounted on bed. The sheet metal work piece or blank is placed between the blank holder and die. The blank holder force is defined by controlling the compression of the suspension while the ram compresses it by die force. The punch penetrates into the blank holder and die as the ram extends.

2.4.3 Force measuring in deep-drawing

The task for this thesis is to produce a system for observing the deep-drawing process in more detail and to provide information for analysis. The advantage over the previous method is that instead of only examining the results of the process, the behavior of the material can be recorded for each moment. The different characteristics combined, a more complete evaluation of the formability of the material can be performed. Because of the complexity of the different stress – strain states in a deep-drawn object explained in chapter 2.3.1, the measuring of input drawing forces seems a much more practical exercise than determining material characteristics based on theoretical models.

In modern large scale, rapid manufacturing the observation and control of the process leans more on the current information from the production than on the information about the product quality examined afterwards. While it is possible to determine most of the stresses in the specimen theoretically, an approach where the actual force applied by the deep drawing press is known at each time provides much more practical knowledge about the materials behavior during the process. When the force data is coupled with the information about the penetration of the punch into the die, different materials or different shapes of the same material can be directly compared to each other based on how they behave at a particular position of the punch. Additionally, the different deep-drawing tests could even demand information about the input forces and spring-back at the end of the draw. With the introduction of numerical data interpretation and recording, numerous tests can be conducted at a rapid rate and results are instantly available for analyzing.

2.4.4 Implementation method

The forces in the process are measured through sensing elements that are required to be fitted into the machine i.e. the deep drawing press. In order to gain accurate and exact results suitable for analyzing by computer software, the force sensors must be directly connected to the whole of the force transmitting area i.e. completely transmit the force through the sensors as measuring partial forces often yields false results. (Dr. K. Reid et al. 2011, 1148). This means that the sensing must take place in an additional element that is situated between the tool and the hydraulic press cylinder, or the strain of an existing tool part is measured for the whole of its section.

2.4.5 Measurement points

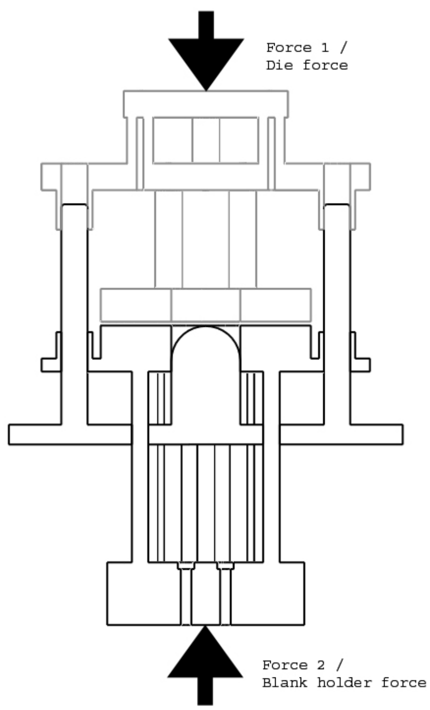

Figure 5 Locations for measuring force in the target press

In practice two forces are of interest, punch force and blank holder force (Fig. 5). The forces the two hydraulic cylinders of the press experience are the only directly definable forces of the process. The tool outlay of the press at the Sheet Metal Centre offers the option of measuring the force at which the die is pressed against the blank holder (F_1) and the force to which the blank holder is subjected (F_2). Accordingly to Newton's third law of motion, the subtract of these two is the punch force, as in Eq. (1).

$$F_{punch} = F_1 - F_2 \quad (1)$$

The blank holder force is directly the compressive force experienced by the blank holder. In addition, the displacement of the cylinders is wanted to be measured. This is achieved by connecting a rod-type displacement transducer between the static base of the cylinder and the moving piston.

3 MEASUREMENT TECHNOLOGY

A physical property such as force can be quantified by measurement through a device that converts the amount of force into something analyzable, i.e. reading of a gage or an electric property, such as resistance. A "sensing element" or "sensor" receives the energy of the measurand as input. The input is then transformed into another form of energy in the "transduction elements". After conditioning, such as amplification and filtering, the output energy can be transferred as measurement signal into the readout for analysis of the measurand. The device capable of the sensing-transforming actions is hence called a transducer. (Dias 1995, 5.1)

3.1 Measuring chain

While a single sensor or transducer cannot alone produce electronically analyzable information about a measured quantity, they are arranged into members of a measuring chain (Fig. 6). A measuring chain consists of acquisition of the measured quantity, matching of the measurement signal, and output of measurement. The members of the chain are all measuring instruments. (Hoffmann 1989, 136)

The transducer is the acquisition stage of the chain, where energy of the measured quantity is transformed into electric signal. The signal is matched by the measuring amplifier, amplifying the voltage level, formulating it by filtering out undesired effects and when required, digitizing it by analog-to-digital conversion (ADC). Finally, the signal is fed into the output device which visualizes the measured quantity, records it, counts it or sends it further to subsequent phases such as data networks.

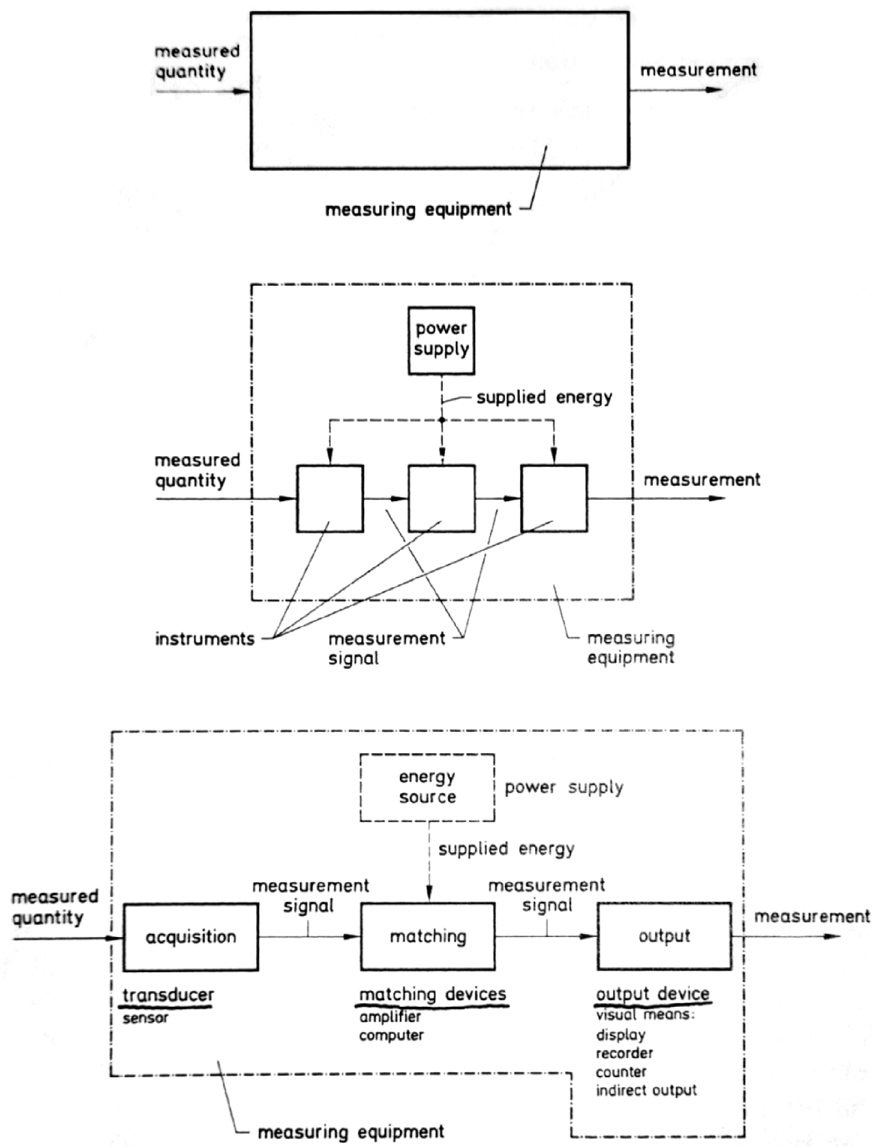

Figure 6 Measuring equipment or "chain" (Hoffmann 1989, Fig. 6.0-1)

3.2 Signal acquisition

The sensing elements in a measuring chain produce the electric signal from the measurand energy for the transducer to transform. Various sensing elements are used, each relying on a different method of sensing and each method is a viable solution for a particular physical property measurement. For the purposes of this thesis, transducers that employ electric resistance and inductance are of interest.

3.2.1 Strain gage measuring

A strain gage (Fig. 7) is a metallic strip which is attached to the surface of an element for which the strain when loaded is wanted to be measured.

The strain gage is an electroconductive metal strip which changes its resistance with mechanical strain, effect of tensile or compressive stress. “The measurement…assumes that the strain is transferred without loss to the strain gage” (Hoffmann 1989, 12). Therefore a close bond with the object is required and generally achieved with the use of an adhesive. When connected to a regulated current, change in resistance of the strain gage due to input quantity changes the measured voltage over the gage’s connectors, i.e. output.

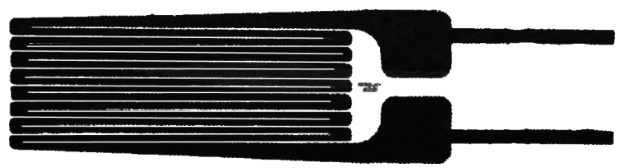

Figure 7 A typical strain gage strip, make HBM (Hoffmann 1989, Fig. 1.0-7)

Strain gages have an important characteristic called gage factor (k-value) which is essentially the sensitivity of the strain gage. Sensitivity for the strain gage is the ratio of relative change of resistance to the strain, i.e. how large a difference of resistance is formed when the strain changes. Its unit can be written Ω/Ω (ohms per ohms), but the gage factor is often given without a unit.

Strain gages are strongly influenced by external effects, foremost temperature of not only the strain gage itself, but the measuring point (Hoffmann 1989, 90). Inadequate measures to compensate for them result in erroneous measurements or even inhibit the use of strain gages. Among many effects, thermal expansion occurs in all materials and if it is restricted, stress is formed. Thermal output effects can be compensated by circuit configurations to some extent, but thermal effects extend into amplifier electronics and further. Furthermore, the sensitivity of the strain gage is dependant of the operation temperature. The operational temperature range of strain gages is therefore limited. (Hoffmann 1989, 51, 67, 151).

3.2.2 The Wheatstone bridge circuit

The sensing elements in transducers, regardless of the measured quantity, are often arranged into a circuit orientation known as Wheatstone bridge circuit (Fig. 8), named after the inventor Sir Charles Wheatstone (1802 – 1875). By employing the Wheatstone bridge circuit, changes in resistance of the order 10^{-4} to 10^{-2} Ω/Ω can be measured with a great accuracy (Hoffmann 1989, 126). This characteristic is therefore advantageous for physical measuring purposes.

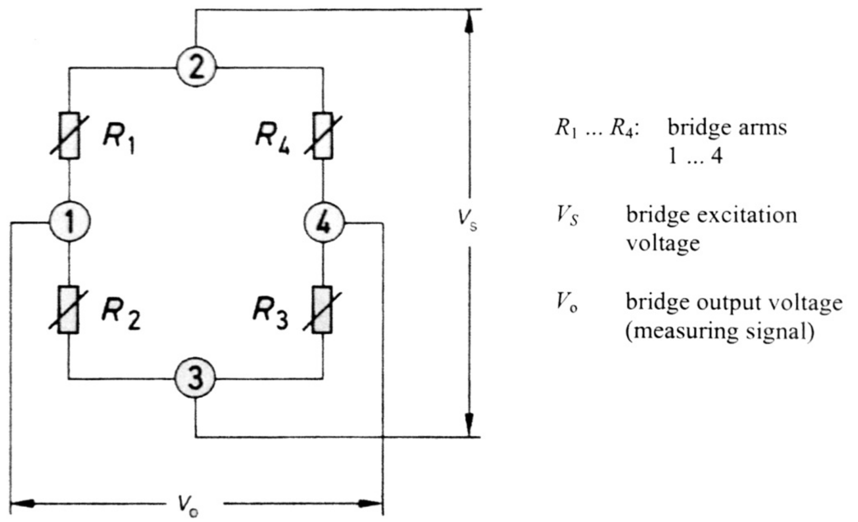

Figure 8 The Wheatstone bridge circuit (Hoffmann 1989, Fig. 5.1-1)

While resistance is difficult to measure accurately, the function of the Wheatstone bridge circuit bases rather on the balance of the bridge resistances. Either “the absolute value of a resistance by comparison with a known resistance” or “relative changes in resistance” are determined (Hoffmann 1989, 126). The bridge is commonly supplied with a constant, known voltage. The measured output voltage is in proportion to the changes in the resistances. When a member of the bridge changes its resistance, the bridge is unbalanced and an output voltage is produced. The Wheatstone bridge can be excited using alternating or direct voltage. The output is similar to both direct and alternating voltage, proportional to the bridge unbalance.

3.2.3 Transducer sensitivity

An important characteristic of transducers is the sensitivity which is commonly given in unit mV/V. Sensitivity refers to the amount the output changes in proportion to changes in the input (Coverstone 1995, 4.2). A more sensitive transducer produces a larger difference in output energy than a less sensitive device, which is good for measurements that deal with demands for great precision at a small range of input. At wider ranges, a less sensitive transducer would be required so that enough output signal is available at the maximum input. For strain gage transducers the sensitivity is usually the same as the k-value of their strain gages, unless additional amplifying electronics are integrated, commonly of the order 1 to 4 mV/V. Electromagnetic transducers have a large sensitivity due to the unique characteristic the magnetic transfer, of the order 80 mV/V.

3.2.4 Force transducers and load cells

A strain gage force transducer is a structure which is designed to predominantly strain in the direction of the loading. Strain gages attached in the elements intended to strain the most linearly sense the strain as explained above. Term “force transducer” commonly refers to a load cell (Fig. 9) that has several strain gage groups to eliminate other types and directions of force other than the desired measurand (HBM Finland, seminar 30.05.2011). The input energy of a force transducer is the physical force itself and the output is an analog voltage signal. The transducer operates by strain-gage principle and is therefore externally powered. The output follows a nearly-linear function up to the proportional limit, that is strain linearly proportional to stress.

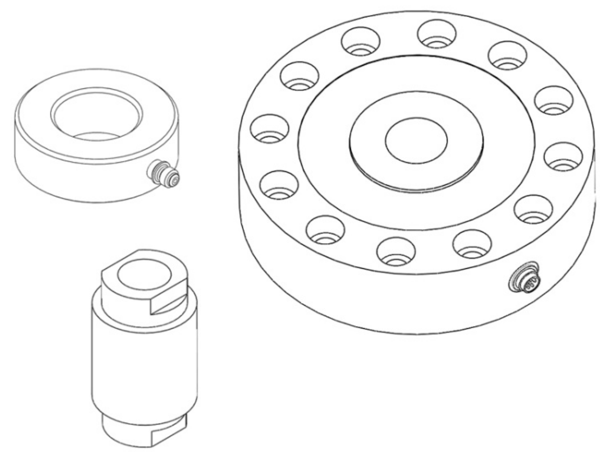

Figure 9 Different shapes of strain-gage load cells

Commonly made of hardened tool steel, the capacity of the structure can be made very large, available capacities ranging from a few grams through 1500 tons (13350 kN) (Smith & Associates 2006, 2). Force transducers and load cells are commercially available in many shapes and mounting principles, the most common high-capacity type being perhaps the pancake (as in Fig. 11). The common lower-capacity form is the S-block. Other types include a rod construction, particularly suitable for tensile loading, a low-profile washer-shape for compressive loads, a small button-construction for low-capacity, sensitive purpose, etc.

Load cells require an accurate calibration for use in research purposes but as such offer reliable performance tolerant to changes in environmental conditions. Furthermore, advanced load cells have a tolerance for slight misalignments of the load direction (e.g. unparallel contact surfaces, off-center loading), without unknown effect on measurement accuracy.

3.2.5 Displacement transducers

A displacement transducer is used to measure travel, or displacement, along an axis. Different physical properties are utilized in tracking displacement, including resistance (potentiometer), capacitance and inductance. The linear variable differential transformer (LVDT) (Fig. 10) consists basically of three coils, a primary coil and two secondary coils, and a moving armature core. Alternating current excites the primary coil, which induces current in the secondary coils, hence the name transformer. As the core moves, the two secondary coils produce different output voltages. It is this difference that is used to determine the displacement of the core. The measurement bases on magnetic difference, hence the resolution of a LVDT is infinite and accuracy excellent. For this reason it is also the most popular type of displacement transducer. (Sulivahanan et al. 2008, 760)

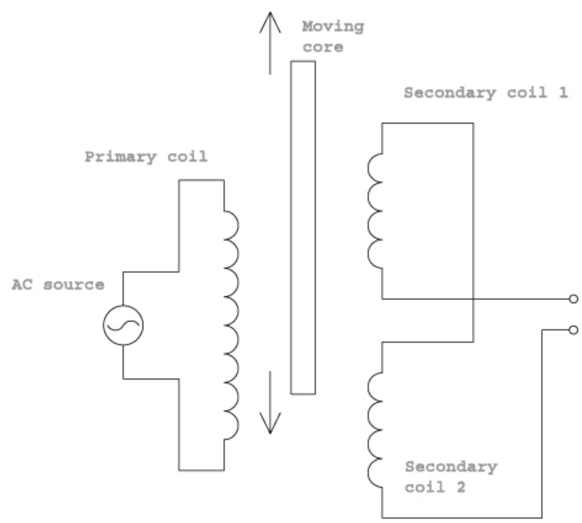

Figure 10 An inductive displacement transducer

In the construction of a typical inductance displacement transducer, a metal rod acts as the armature core and the coils are wrapped inside a hollow metallic cylindrical body.

3.2.6 Transducer supply

Transducers require a voltage source in order to produce a measurable signal that is in relation to the property wanted to be measured, force and displacement in this case. A measuring amplifier supplies a constant voltage to the transducer's sensing elements. Amplifiers have means setting the desired values of supply voltage, or excitation, and adjustments for zero point value and other measuring parameters. Commonly transducers are designed function in the range of 0 V - 10 V, depending on their sensitivity. Measuring amplifiers supply either a direct or an alternating voltage. As mentioned above, the output voltage of a Wheatstone bridge circuit transducer is similar to both excitation methods. However, the use of alternating excitation voltage, known also as carrier frequency excitation, offers the advantage of reliable measurements particularly in surroundings where external disturbances, such as electromagnetic radiation or mechanical high-frequency vibration can be expected.

The issue with direct voltage excitation is that all effects of the measuring circuit, including the desired quantities but also the external interference, are fully amplified. The measured signal is therefore superposed with various values of the measured quantity that are not necessarily in any relation to the actual desired quantity. Because the measuring circuit, and particularly the Wheatstone bridge circuit produces a similar output disregarding whether it is excited by a direct or alternating voltage, the circuit is easily supplied with an alternating voltage for which the amplitude and frequency are accurately known. When measuring the output voltage, only the values of only the same frequency and narrow sidebands are recorded. Common carrier frequencies are 225 Hz and 5 kHz (also 4.8 kHz). Effects of other frequencies, such as the common mains frequency of 50 Hz are not present in the measurement signal and the result depicts the measured quantity more accurately. (Hoffmann 1989, 133)

3.3 Signal matching and output

The output of a transducer is a signal that represents the measured property in electric form, usually voltage which is accurately measurable with great resolution. The output level is dependant of the supply voltage and sensitivity of the transducer. However the signal is still in “raw” format with a low voltage level, or low amplitude with carrier frequency excitation method. Undesired disturbances external to the measurand might also exist in the signal. Therefore the signal is amplified and conditioned. The transducer supply and amplification is often built into the same unit, a measuring amplifier.

In the measuring amplifier, the signal is changed with a gain to produce a higher-level voltage for analog signal-processing hardware to function. But practical amplifiers and attenuators produce also errors in the signal, reducing its “quality” (Hilton 1995, 9.1). Therefore an ADC (analog-to-digital conversion) module in the measuring amplifier digitizes the signal for software-based signal conditioning. The measured quantities, such as force and displacement are specific for each moment of the process. Thereby the flow of data is continuous for the time of the measurement operation. The more frequently a single value is recorded, a more precise representation of the measurand can be formed. For this a measuring amplifier with fast sample rate is required.

Modern physical measurements are carried out with the help of a measurement amplifier that simultaneously acts as a recording device or transmits the data to a computer. Naturally, a display showing the readings could be added to the system as an interface for the operator to refer to during the process.

3.4 Calibration

Calibration of measuring equipment is “the comparison of measurement and test equipment…to a measurement standard of known accuracy to detect, correlate, report, or eliminate by adjustment any variation in the accuracy of the instrument being compared” (Workman 1995, 2.1). When measuring equipment is calibrated to a certified degree, the desired quantity can be measured reliably with a certain accuracy.

A level of confidence in the data produced by the measurement equipment is required in research work. Therefore calibration of the equipment is an important matter, as trustworthy statements about the research results cannot be made if the measurement data does not represent the real world quantities with known accuracy. Measuring equipment manufacturers conduct initial calibration to their products in order to verify that device is functioning as intended, i.e. that it has the accuracy required to perform its intended task. A calibration verification delivered with each device is a proof of its performance and characteristics at the time of delivery.

As do all mechanical elements and devices, so does measurement equipment change its behavior with time. The change is due to mechanical wear, electrical component aging, operator abuse and unauthorized adjustment (Workman 1995, 2.5). Therefore subsequent periodical calibrations are required to restore the “confidence” in results the carried-out measurements produce. Calibration is conducted by the manufacturer, to whom the equipment must be sent, or by on-site calibration service who verify the performance of the devices by comparison to reference equipment with a known, more accurate performance. The calibration equipment is governed by standards formed by metrology offices.

All devices used in this thesis are calibrated by the manufacturers and valid for 1 year from the delivery date.

4 SOLUTION

The goal of this thesis is to produce a measurement system for quantities of force and travel in the target deep drawing press. The original outlay of the press does not include any other means of measuring press force or tool displacement other than a hydraulic system pressure gauge and limit switches for maximum and minimum travels of the punch and die. The solution should fulfill the required measurement tasks, be economical and easy to assemble. The possibility for tool changes is a necessity that must remain. Initially it was apparent that additional elements for measuring must be introduced into the press or the press modified. The most important property in the design of the measurement system is the force measuring. Due to the hydraulic system and more importantly its AC-motor driven pump, a source of electromagnetic radiation, disturbances to the electric measurement equipment must be taken into consideration. The different solution options are considered in the next chapters.

4.1 Hydraulic pressure measurement

A method of measuring force which the hydraulic cylinders apply would be to measure the hydraulic pressure in each system and deduce the according cylinder force. This solution would require only the addition of a pressure sensor, basically an applied load cell, in the line of the extension side of each cylinder and recording the value via measurement data acquisition. The advantage of this method is the great simplicity of assembly. Furthermore, accurate sensors (< 0,1 % of FSO) are available at economical prices.

However, determining the cylinder force based on the measured value of pressure is highly prone to errors that result in intolerable inaccuracies for materials research work. The causes of errors include changes in the compressibility and other characteristics of the hydraulic fluid due to environmental conditions, the internal and external friction of the hydraulic system, pressure shocks caused by the pump (Parr 2000, 21). Furthermore, as the cylinders support the tools in compression (lower) and tension (upper), the exact reference zero-point of fluid pressure for force measurement is hard to determine. As explained in chapter 2.3.2., the force measurement is required to be carried out in an element having its full cross-sectional area under the load. Following the rule is not possible for this method. As other solutions exist, the solution for measurement of force through measuring of hydraulic pressure is abandoned.

4.2 Strain gages

The application of strain gages on a certain press element would remove the need for modifying the structure of the press through new additional parts. Several locations in the deep drawing tool could be considered for the surface of strain gages as they are easily accessible and represent forms for which the elasticity or spring coefficient is relatively straightforwardly calculated. However, the tools must be changeable and due to the structure of the press, the possible locations are reduced to those for which the behavior under loading is not possible to be determined with accuracy. The locations would be the press frame, some point of the cylinder mounts, cylinder to push plate flanges, among others. Another possibility would be the manufacture of own transducers for the press. The shape of the structure could be the best suitable for the case, and the transducer designed to perform exactly to required needs.

However, ensuring the uniform deflection of several elements applied with strain gages is fairly impossible and the design of load cells or force transducers is that vast of a task, that it would expand beyond the scope of this Bachelor’s thesis. Strain gages are delicate instruments, highly sensitive to changes in temperature, which are common in the facilities, and to external stresses which are carried into the press frame from the hydraulic system. The application of a strain gage is a delicate operation as well, and mistakes such as disorientation, and bad adhesion to surface would result in erroneous measurements. Each strain gage system should therefore be calibrated with use of calibration instrumentation, which is expensive for a single custom layout (Hoffmann 1989, 135). Strain gages are most suitable for more experimental purposes. As the optimal environment for strain gages, or for the manufacture of own transducer could not be easily organized, the use of bare strain gages was abandoned.

4.3 Load cells

The use of strain gage based load cells was determined to be the best solution method for this case. While strain gages represent the best performance/economy ratio for most force measurement tasks, the difficulty in their application and resulting high risk of measurement errors directs the attention towards commercial measuring equipment manufacturers that offer pre-calibrated, high-accuracy, high-capacity load cells. Load cells come in a variety of shapes, a pancake-like cylinder structure being the most common. The typical structure comprises of cylinder with machined-through slots, forming an outer and an inner ring. A single or several groups of four strain gages are applied to the connecting arches and connected in the Wheatstone bridge circuit (HBM Finland, seminar 30.05.2011). The attachment of the load cell is specific for each model and different manufacturers offer their own orientations of bolts and patterns. As expected, the suitable load cell should besides the required load capacity have suitable form and mounting.

It was determined that the load cell should have the capacity of 50 tons (500 kN) as the press is used for deep drawing research work. Also, load cells with capacities more than 100 tons tend to have large dimensions and therefore are not suitable to be fitted into the press.

4.4 Selected equipment

The selection of the equipment bases on the criteria of technical specifications, ease of assembly/use, purchase price and availability. The performance in measurement and dimensions of a transducer are the main criteria, as they effectively govern the design for assembly of the press and in overall, the measuring tasks that are capable to be performed and with what level of accuracy. The selected equipment was purchased by the Sheet Metal Centre through Elkome Systems Oy (Futek load cells) and HBM Finland (Measuring amplifier/data acquisition, measuring software, displacement transducers).

4.4.1 Force transducers

Force transducers and load cells were browsed from the vast selections of manufacturers such as Gefran, HBM, GTM, Tokyo Sokki, Futek, Kyowa, Kistler, Lorenz and Flintec. Each manufacturer offers various models with different characteristics both in measurement tasks and in mounting principle.

The choice of load cell eventually led to the model LCF550 by Futek Advanced Sensor Technology, Inc. (Fig. 11). The maximum capacity of the LCF550 is 444,8 kN, which is suitable for the task. Nonlinearity ±0,1% of the Rated Output corresponding to rough estimate of accuracy ±444,8 N is also tolerable for the task. (Data Sheet, App. 1) The Futek LCF550 load cell was selected as it fulfills the required loading and measuring capabilities, is reasonably priced and available directly through a Finnish distributor, Elkome Oy. An important characteristic of the LCF550 is that it is suitable for carrier frequency excitation.

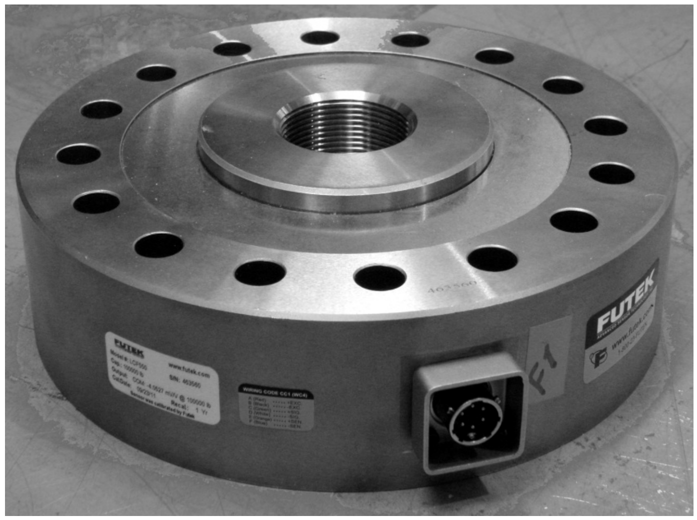

Figure 11 Futek LCF550

4.4.2 Displacement transducer

The function for the displacement transducers is to provide the information about the travel of the hydraulic cylinders, subsequently the displacement of the tool. The basic type of an inductance displacement transducer of a rod-type linear variable differential transformer will be suitable for the task. The selected displacement transducer is the HBM WA inductive displacement transducer with a 300 mm travel (Fig. 12), with accuracy class 0.2 (linearity ±0,2 % FSO) (HBM GmbH 2001, 7). As an LVDT, it is particularly suitable for use requiring high durability and precision (Appx. 2). The prices on displacement transducers do not vary as much as for force transducers or load cells, hence following the advice of HBM Finland's representative the WA was chosen as it fulfills the required measuring capabilities and is simple to connect with the measuring amplifier MX410 as they are by the same manufacturer, HBM. The construction of the transducer is robust, e.g. the moving rod is free inside the transducer body and completely removable, offering protection against damage in the case of reaching maximum extension.

Figure 12 HBM WA/300-L

4.4.3 Measuring amplifier and data acquisition

Requirements for the measuring amplifier are at least 4 individually configurable inputs, transducer supply by carrier frequency excitation, easy connectivity to a PC software, and additionally, 4 analog outputs (Appx. 3). The QuantumX measuring amplifier family by HBM was among the possible solutions especially due to the great level of integration between hardware and software they offer. The decision led to the choice of QuantumX MX410 amplifier (Fig. 13), which is a 4-input universal amplifier, particularly designed for carrier frequency technology. It also has 4 analog outputs which are important for future incorporation of the press measurement system with other devices, such as the GOM ARAMIS optical deformation analysis system, in use at the Sheet Metal Centre. The data acquisition is carried out with the HBM catmanEasy/AP-software (Fig. 14), through which the complete measurement operation can be operated, the results recorded and visualized for immediate observation and later analysis. The software requires no programming but allows for the user to create sequences where pre- and post-triggers follow the input quantity and accordingly start and stop measurements with set data points.

Figure 13 HBM QuantumX MX410 measuring amplifier

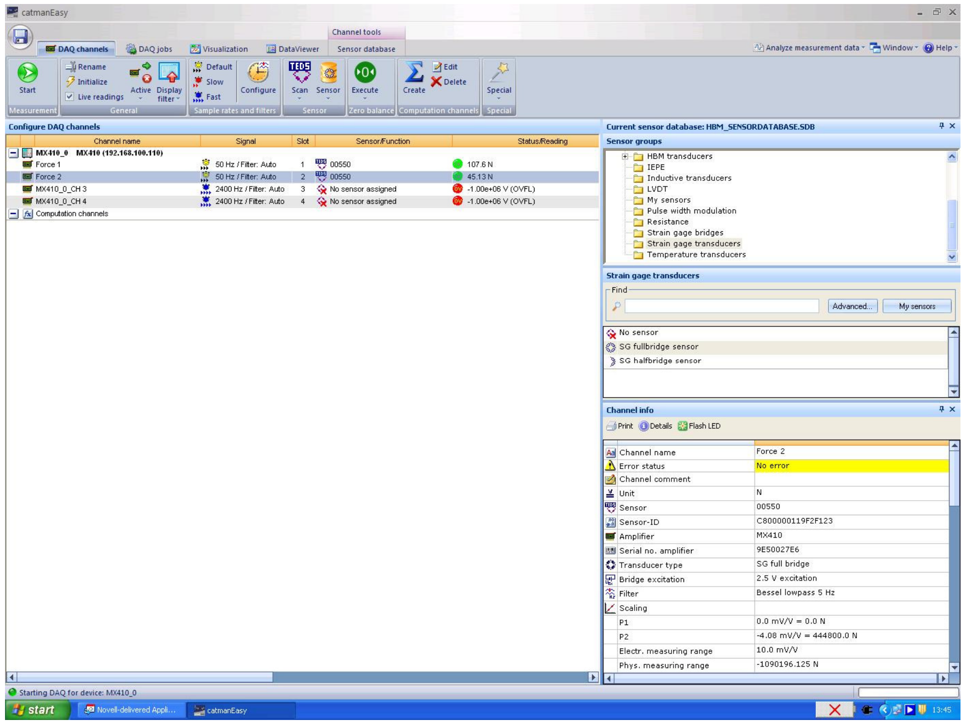

Figure 14 HBM catmanEasy/AP measuring software interface

A great advantage of HBM is the TEDS-technology (chapter 5.2.1) which essentially is a chip in the transducer connector, where information about the type of transducer is recorded. A TEDS-equipped transducer is identified by the measuring amplifier at the time of connection and appropriate parameters such as supply voltage automatically set. TEDS-chips are possible to be attached to non-HBM transducers too, and the information manually inserted.

5 TECHNICAL DESIGN

Equipment selected for use in the assigned measurement task was presented in the previous chapters. As it became apparent, the solution requires modifications and additions to the deep-drawing press. The design for the accommodation of the transducers involves the needs of various aspects to be fulfilled, some of which contradict each other. The designed structure must allow the equipment to function in its intended manner, minimizing errors in measurement but in a way that is applicable in reality. For instance, the structure should be straightforward to assemble, requiring as few special components as possible but not raise uncertainty about measurement accuracy. Most importantly however, the structure must withstand the loading it is subjected and be safe for operators.

The redesign of an existing structure requires the simultaneous attention towards both the limitations and the requirements. There exists a limit where the amount of changes to the existing structure is not feasible or economical anymore. Similarly, equipment that is available is required to fulfill its intended functions but should be of tolerable purchase price. Special made-to-order components are expensive.

Commonly the ideal solution is hard to come by for cases that are not designed anew from the ground up. Therefore careful and innovative approaches must be made in order to find an effective solution where the required task is fulfilled without conflicts at a reasonable price.

5.1 Mechanical design

The major factors governing the design of the force and displacement measuring system are dependent on both the selected solution and implementation method but also the commercially offered products and their characteristics. For this case, two load cells as well as two displacement transducers with defined specifications and measuring capabilities are required. However, as important as their measuring capabilities are, so is their designed mounting method. The changes to the existing press structure and the need for new manufactured elements should be kept at a minimum. With measuring equipment comes the requirement for accurate specific mounting for the equipment to function as they are calibrated. This effectively means that the transducer must in all cases be mounted according to the manufacturer's instructions. Otherwise costly recalibration by the manufacturer is required immediately before any reliable measurements can be done.

5.1.1 Transducer mounting

Regarding the mechanical mounting and assembly, the load cells require the major attention. The displacement transducers are mounted to measure the travel of the hydraulic cylinder and as such only require mounting blocks for attachment to the cylinders. The technical drawing for the mounting blocks is in appendix 4.

The load cells will be mounted in between the hydraulic cylinders and the push plates in both the upper and the lower assemblies. A difference between the upper and lower assemblies is that when the upper hydraulic cylinder is retracted, i.e. raised, the load cell must hang the upper tool assembly. The chosen load cell LCF550 is suitable for both tension and compression, which enables it to withstand this loading. Another design aspect is that the stack of load cells and other elements should be kept as low as possible, because of the limited travel of the hydraulic cylinders. Any further additions to thickness would reduce the travel and affect the possible deep-drawing depth.

The LCF550 (appendix 1) is a pancake structure, having 16 M12 ISO 4762-suitable bolt holes in a circle pattern around its outer ring and a single M42x2-threaded centre hole providing the mounting for the inner ring. For both the upper and lower hydraulic cylinders of the press an orientation where the inner ring of the transducer faces the cylinder piston flange is deemed better. An opposite orientation would have required a wider flange, prone to deflection towards the centre of the transducer during the press compression unless the flange would be stiff and thick. Thereby, the inner ring would be attached into the cylinder piston flange.

The issue with the single bolt central mounting as in the LCF550 is that angular alignment of the outer ring bolt holes cannot be guaranteed after the load cell has been mounted on if the bolt is stationary in the structure. The dimensions and the requirement for a low assembly make the use of an actual standard M42x2 bolt very difficult. The use of a special threaded block is therefore needed, which should be solid, or free to rotate but have faces for tightening, e.g. with a wrench, the transducer acting as a nut. The inner mounting of the load cell is solved using a threaded cylinder adapter connecting the load cell to a flange. The adapter is the same for both the upper and the lower assembly but with different connecting methods, each explained in chapters 5.1.2 and 5.1.3, respectively.

The parts are required to have sufficient smooth finish on the contacting surfaces between two parts, but more importantly a good analogy of parallelism and concentricity of features to reduce misalignment of loading. The best method of reducing nearly-undeterminable sources of measurement error is to methodically eliminate the possibilities for them to exist.

5.1.2 New upper assembly

The new upper assembly (appendix 4) comprises of the upper cylinder cushion plate (1), the upper flange (2) , the adapter (3), the load cell Futek LCF550 (4) and the upper push plate (5).

To enable the changeability of the drawing tool, the load cell must be situated between the cushion plate and the push plate. The load cell is attached to the push plate with 16 M12x90 ISO 4762 bolts, necessitating corresponding threaded holes the size M12x1.75 to be made (Appendix 7) in the push plate.

The adapter mounted (Appendix 8) to the center M42x2 hole inserts into the new upper flange (Appendix 9) and is welded into place with beads running the two flange-facing circumferences of the adapter (Appendix 10). The radius of the weld is calculated to be sufficient enough by a very large margin to the required; a = 3 mm vs. a = 0,0232 mm (Niemann et al. 2005, 293 eq. 7.3).

The upper flange and the cushion plate are connected by 8 M20x80 ISO 4762 bolts with washers and ISO 7042 torque nuts. The slots in the flange allow a rotation of 22,5° for the assembly that is enough for the load cell and push plate to be always adjustable to an orientation where the push plate T-slots are parallel to the press bed T-slots. No modifications are required to the cushion plate which attaches to the hydraulic cylinder by bolts.

5.1.3 New lower assembly

The lower assembly (Appendix 5) comprises of the lower push plate (6), the load cell Futek LCF550 (7), the adapter (8) and the lower flange (9).

The loading in the tool is transmitted to the lower hydraulic cylinder by 16 rods that run through holes in the press bed (Fig. 4). The rods lay freely on the push plate meaning in no case tensile forces could be created with the lower cylinder. Thereby, an assembly that is not rigidly mounted solves the problem with the alignment of the load cell outer ring holes because the load cell is free to rotate.

The load cell is attached to the push plate with 16 M12x90 ISO 4762 bolts, necessitating for corresponding M12x1.75 holes to be made in the push plate (Appendix 11).

As mentioned in chapter 5.1.1., the adapter to connect the load cell and the flange is the same design for both assemblies. Here, the adapter inserts into the lower flange (Appendix 12) but is not fastened by any means. Instead, it rests on the flange surface and is to free to rotate about its longitudinal axis. Because no tensile loading exists and the cylinder never accelerates downwards fast, i.e. close to the gravitational acceleration, the assembly will never “hop” out the flange. However, if the press is to be moved the assembly must be secured externally by rigging slings or similar to prevent the assembly dropping out. The flange is attached to the hydraulic cylinder by 4 M16x60 ISO 4762 bolts.

5.1.4 Displacement transducer mounts

The displacement transducers are compressed and attached from their bodies in the bases of the hydraulic cylinders with nylon mounting blocks. The blocks are mounted with two M4x40 ISO 4014 bolts . The mounting blocks (Appendix 6) are made of nylon to allow the transducer body to slide, should the moving rod reach minimum travel, preventing damage to the transducer. The moving central rod of the transducer has an M4 thread at its end which is attached into the proximity switch beam of the cylinder. The corresponding threaded M4x0.7-holes are required to be made into the beam for the rod, and to the beam slider guide for the mounting blocks.

5.2 Electronic installation

Due to the highly integrated electrical system of the HBM products, the system requires little work to be done. All connections are by plugs and the cables are delivered ready to operate by the manufacturer, except for the Futek load cells where the wires were ordered with the other end free. Futek uses the six wire circuit connection as does HBM, but a Bendix-type connector plug while HBM uses the Sub-D-plug. Therefore the plug suitable for connecting to the amplifier should be assembled and connected to the connector wires (Fig. 15).

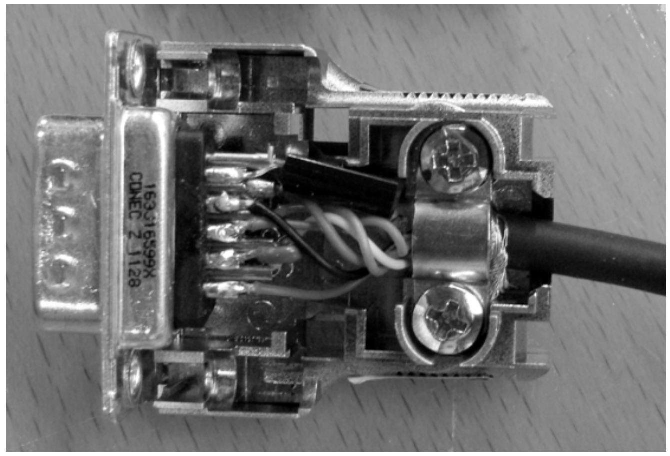

Figure 15 Sub-D-plug with LCF550 wires and TEDS chip connected

The six-wire transducer circuit comprises of the +excitation, -excitation, +sense, -sense, +signal, and -signal leads. The excitation and signal leads serve for the input and the output voltages of the Wheatstone full bridge circuit in the transducer. The sense leads account for compensating the cable resistances that would otherwise lower the supply voltage.

5.2.1 TEDS

One advantage of the HBM products is the possibility of using the TEDS (Transducer Electronic Data Sheet) system that is a chip inbuilt either in the transducer itself or the connector plug. It enables storing transducer-specific information which is read by the amplifier immediately setting measuring parameters stored in the chip. Information on the chip includes the measured quantity and its range, type of electrical output signal, sensitivity, characteristics of the relation between the electrical signal and measured quantity i.e. signal filters, excitation voltage, transducer model and manufacturer, calibration date, calibrator, etc. The use of the TEDS efficiently manages that measurements are conducted using the same settings every time, disregarding different users or their varying experience level with measuring technology.

5.3 Software installation

The catmanEasy/AP software is the recommended software for carrying out measurements with the QuantumX MX410 measuring amplifier, as explained in chapter 4.4.3. The amplifier and the PC are connected with a normal RJ45-cable and the data transfer takes place in Ethernet. Therefore a correct set-up of the network is essential for operation.

The set-up of measurement parameters is done through the software, as is the actual conducting of measurement tasks. Visualization objects can be used to view the measurement in real-time, while the data is recorded to a file. The data can be saved and later exported to many formats, including the MS Excel spreadsheet. The analysis of measurement data can be done using the analysis mode of the software.

The software offers also the tool for programming the TEDS in a connected transducer. The LCF550 load cells were programmed with their individual information on the bridge circuit type, calibration sensitivity provided by Futek, measuring unit and range, excitation voltage levels.

6 IMPLEMENTATION

The assembled system of measuring equipment and supporting structure is basically ready for operation immediately. The measuring software catmanEasy/AP allows the zero point of each transducer channel to be set at any moment and virtual computational channels can be formulated using the actual transducer channels to produce directly comparable measurement readings, without post-processing the data. Here, for example, the displacement transducers work in different directions; the upper extends during the drawing operation and the lower shortens. This results in opposing signs (+ and -) of measurement. Utilizing the computational channels, the sign can be changed, among other addible formulations.

6.1 Testing

For the testing, the measuring parameters were set as default (Appendix 13) and the measuring channels named Force 1, Force 2, Displacement 1 and Displacement 2. A computational channel “Punch force” created that simply subtracts measured Force 2, i.e. lower cylinder force and also blank holder force, from measured Force 1, i.e. upper cylinder force and force in the die. Two test samples of different materials were tested using the Nakajima-test deep drawing tool. The Nakajima test tool uses a hemispherical punch to deform the material until fracture. The test is carried out using maximum blank holding, i.e. the flange area of sheet metal does not flow into the die.

6.2 Evaluation of results

The following graphs (Fig. 16 and 17) were formed using the obtained results and bordered in the region of most interest. The measured force is placed on the Y-axis, the unit is Newton (N). The travel of the hydraulic cylinder, moving the tool, is placed on the X-axis, the unit is millimeter (mm).

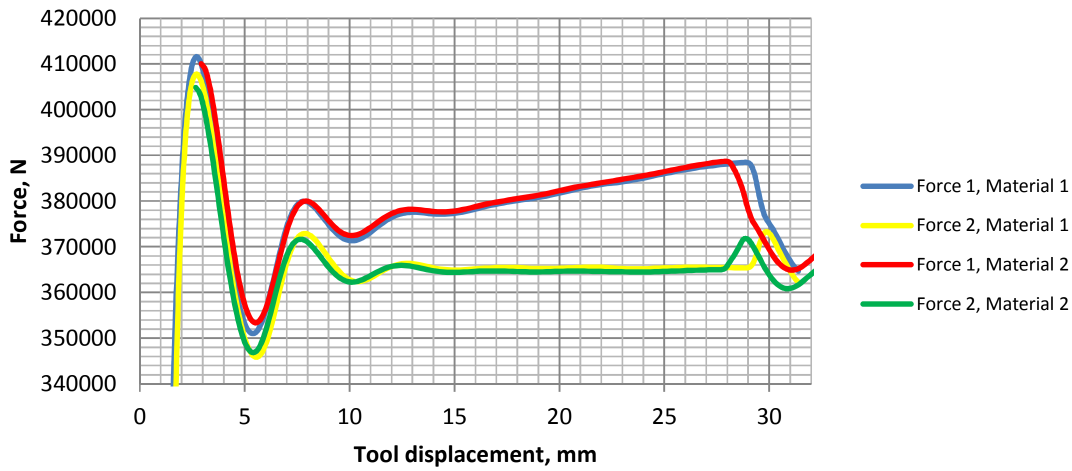

Figure 16 Graph of the measured forces

The graph (Fig. 16) shows the directly measured forces F_1 and F_2 in relation to the displacement of the upper and the lower hydraulic cylinder, respectively (see Fig. 5). The displacement readings were of different sign and situated differently but placed roughly at the same point for the graph. Both measured forces rise abruptly when the die, pushed by the upper cylinder, meets the blank holder, supported by the lower cylinder. The constant blank holding force throughout the test is apparent.

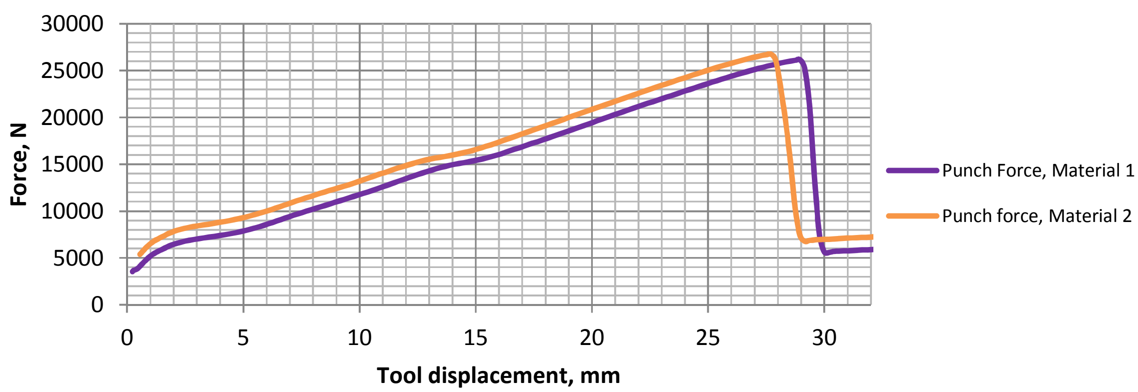

Figure 17 Graph of the calculated punch force

The measured force F_2 is the force experienced by the lower hydraulic cylinder and simultaneously the blank holder force. Therefore it is the other force originally desired to be measured. F_1 indicates the force in the upper hydraulic cylinder, which in the construction is the die force. By subtracting the blank holder force from the die force, the punch force is obtainable, accordingly to Eq. (1). The subtract is graphed in Fig. 17. Thus both of the forces set to be measured are obtained.

6.2.1 Measurement error

For the blank holder force, the theoretical accuracy of measurement is the same as for the load cell, ±0.1% of full scale reading, which corresponds to ±444.8 N. For the punch force, the accuracy of measurement is ±889.6 N as it is a result of two measured values, i.e. 0.1% + 0.1% = 0.2%. The systematic measurement error of the system lies therefore within these values. The random error in measurement cannot be predicted but is most effectively removed when one sample type is tested several times.

7 CONCLUSION

The task for this thesis was to study the range of methods of producing a force measurement system in the deep drawing press of the Sheet Metal Centre and to apply the information in selecting suitable equipment and designing their application.

The work required knowledge about both measuring technology and mechanical engineering to methodically find the solution that functions in the given conditions and fulfills the set requirements. Theoretical expertise was needed to guide the selection of measuring equipment and to constrain the design of mechanical assemblies for proven, reliable performance. Practical know-how ensured that the new structure of the press was designed to fulfill its task well and at reasonable cost. The modifications to the press do not affect its usability for other types of sheet metal formability research.

The selection and design procedure is of very general nature but shows that by utilizing the latest technology, systems with similar or better performance can be constructed without overly extensive knowledge and experience of measurement technology, something of which the field is notorious. The realized system and structure is only possible solution of many and while there exists several other possibilities and design variants, the set target was met as the desired forces and related displacements are now measurable and the data can be used to enhance the materials research work. Judging by the test results the measurement system seems to function as intended.

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FUTEK LCF550 DATA SHEET

FUTEK MODEL LCF550

LOW PROFILE UNIVERSAL PANCAKE LOAD CELL

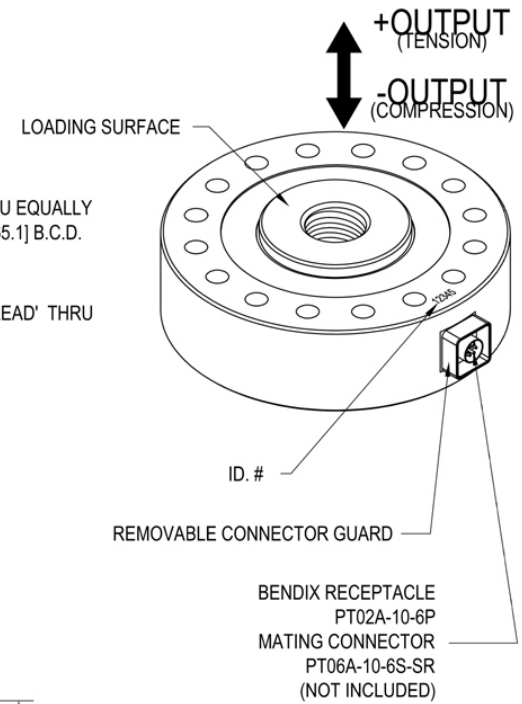
Drawing Number: FI1013-A

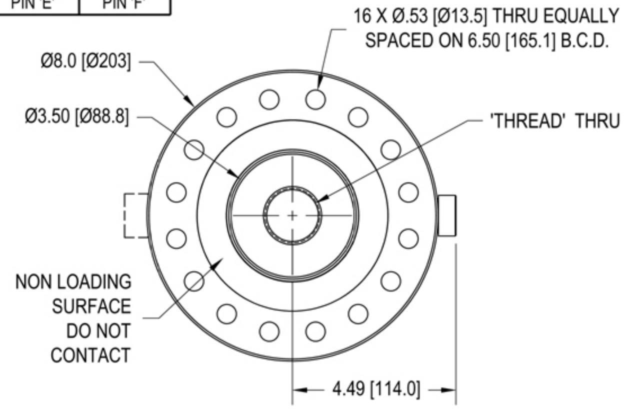
INCH [mm] | R.O.= Rated Output

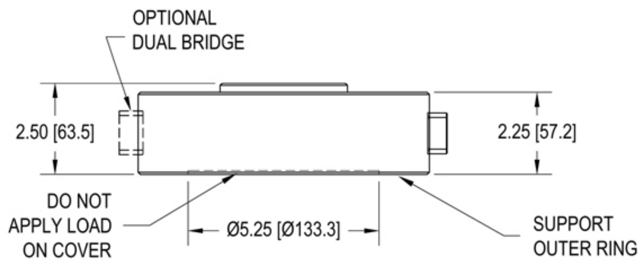
WIRING CODE (CC1)

+Excitation	-Excitation	+Signal	-Signal
RED PIN 'A'	BLACK PIN 'B'	GREEN PIN 'C'	WHITE PIN 'D'

+Sense	-Sense
ORANGE PIN 'E'	BLUE PIN 'F'







STOCK NO:	THREAD	DUAL BRIDGE
FSH02834	1 3/4-12-2B	
FSH02836		X
FSH02757	M42x2-4H	
FSH02835		X

SPECIFICATIONS:

CAPACITY	*100 Klb [444.8 kN]*
RATED OUTPUT	*4 mV/V nom.*
SAFE OVERLOAD	*150% of R.O.*
ZERO BALANCE	*±1% of R.O.*
EXCITATION (VDC OR VAC)	*20 MAX*
BRIDGE RESISTANCE	*350 Ω nom*
NONLINEARITY	*±0.1% of R.O.*
HYSTERESIS	*±0.2% of R.O.*
NONREPEATABILITY	*±0.02% of R.O.*
CREEP	*±0.02% of LOAD*
TEMP. SHIFT ZERO	*±0.001% of R.O./°F [0.0018% of R.O./°C]*
TEMP. SHIFT SPAN	*±0.002% of LOAD/°F [0.0036% of LOAD/°C]*
COMPENSATED TEMP.	*60 to 160°F [15 to 72°C]*
OPERATING TEMP.	*-60 to 200°F [-50 to 93°C]*
DEFLECTION	*0.003 [0.08] nom.*
MATERIAL	*17-4PH S.S.*
WEIGHT	*25 lb [11.3 kg]*

CONNECTOR: 6 Pin BENDIX Receptacle (PT02A-10-6P)

ACCESSORIES AND RELATED INSTRUMENTS AVAILABLE

CALIBRATION (STD)	*5 pt. COMPRESSION; 30K Ω SHUNT CAL. VALUE*
CALIBRATION (AVAILABLE)	*5 pt. TENSION*
CALIBRATION TEST EXCITATION	*10 VDC*

REFER TO LCF555 FOR TENSION BASE VERSION

OTHER AVAILABLE RECEPTACLES & MATING CONNECTORS

BENDIX RECEPTACLE (PCO4E-10-6P)
BENDIX MATING CONNECTOR (PCO6E-10-6S-SR)

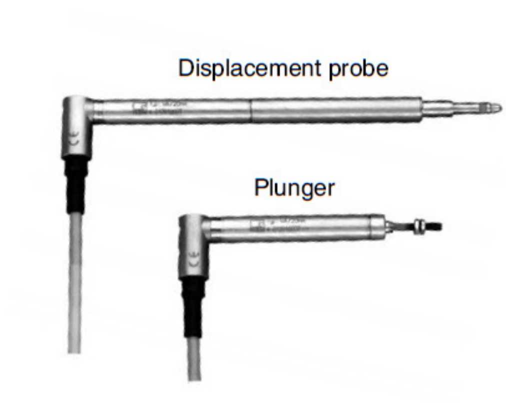
FUTEK
ADVANCED SENSOR TECHNOLOGY, INC.

10 THOMAS
IRVINE, CA 92618 USA
1-800-23-FUTEK (38835)

INTERNET:
http://www.futek.com

HBM WA-L/300 DATA SHEET (PAGE 1)

Data Sheet



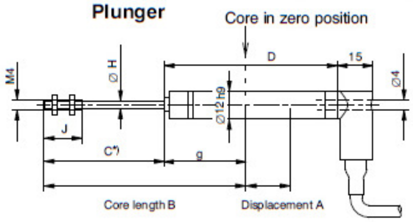
WA

Inductive Standard Displacement Transducers

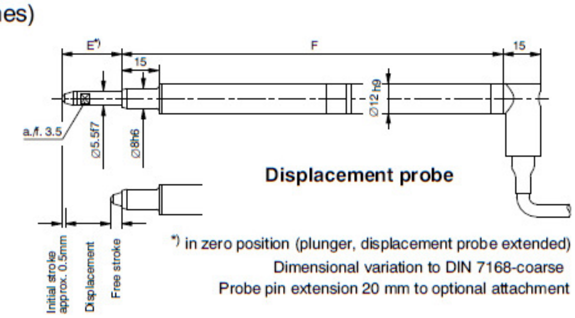
Special features

- Displacement probe and transducer with detachable plunger
- Good thermal stability in the event of temperature gradients
- Space-saving, compact design
- Pressure-resistant transducer for measuring displacement in hydraulic cylinders
- Acceleration resistance ensures long service life
- Option: high temperature version up to 150 °C, low temperature version up to −40 °C
- Output signal of your choice:
  80 mV/V
  0.5–10 V

Dimensions (in mm; 1 mm= 0.0397 inches)



Fitted PVC cable, ∅6, optional length and termination



*) in zero position (plunger, displacement probe extended)
Dimensional variation to DIN 7168-coarse
Probe pin extension 20 mm to optional attachment

	Plunger							Displacement probe		
Measuring range	A	B	C	D	G	∅H	J	A	E	F
0...2 mm	2	75.5	40	69	35.5	1.2	15	2	14	130
0...10 mm	10	66	40	69	26 ± 0.5	3.7	16	10	14	130
0...20 mm	20	87	55	84	32 ± 0.5	3.7	16	20	24	170
0...50 mm	50	117	85	114	32 ± 0.5	3.7	16	50	54	230
0...100 mm	100	180	134	181.6	46 ± 10	3.7	16	100	104	372.6
0...200 mm	200	280	234	281.6	46 ± 10	3.7	16			
0...300 mm	300	380	334	381.6	46 ± 10	3.7	16			
0...500 mm	500	580	534	581.8	46 ± 10	3.7	16			

HBM QUANTUMX MX410 DATA SHEET (PAGE 1)

Data sheet

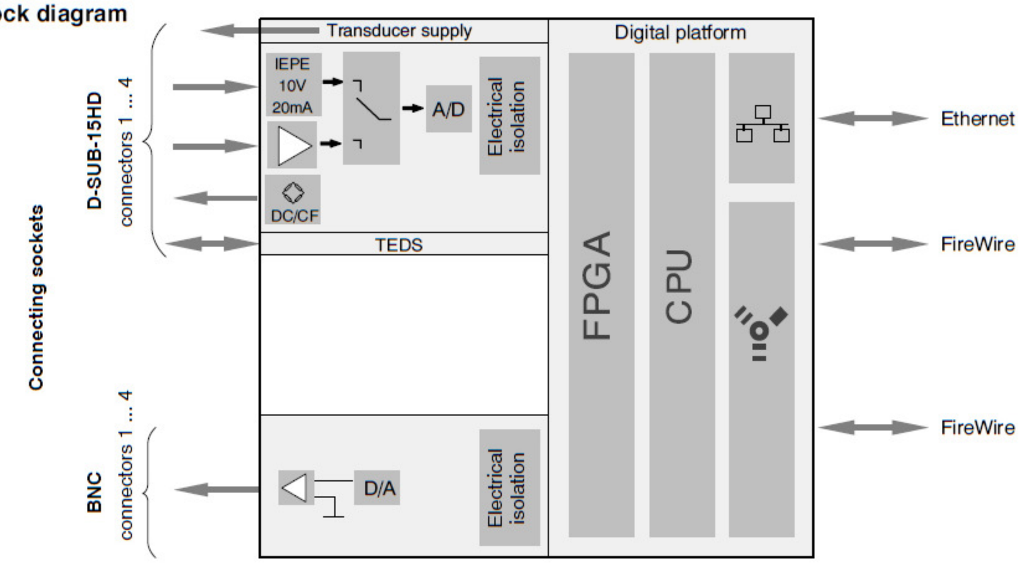
QUANTUMX MX410

Highly dynamic universal amplifier

Special features

- 4 individually configurable inputs (electrically isolated)
- Connection of more than 5 transducer technologies
- Data rate: up to 96,000 Hz 19,2000 with 2 channels
- 24-bit A/D converter per channel for synchronous, parallel measurements
- Active low-pass filter
- 4 analog outputs
- Real-time computation (Peak, RMS)
- Supply voltage (DC) for active transducers: 5 V ... 24 V

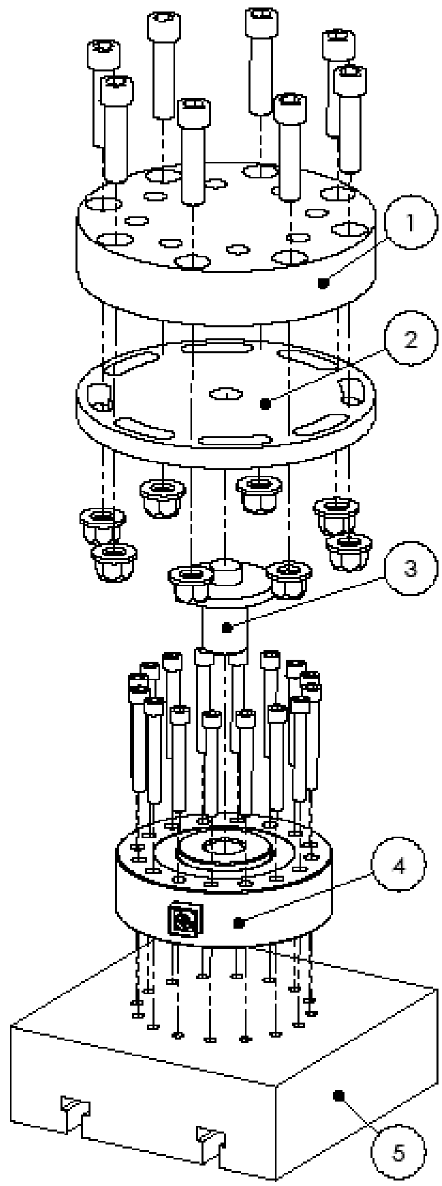
Block diagram



B2612-5.0 en

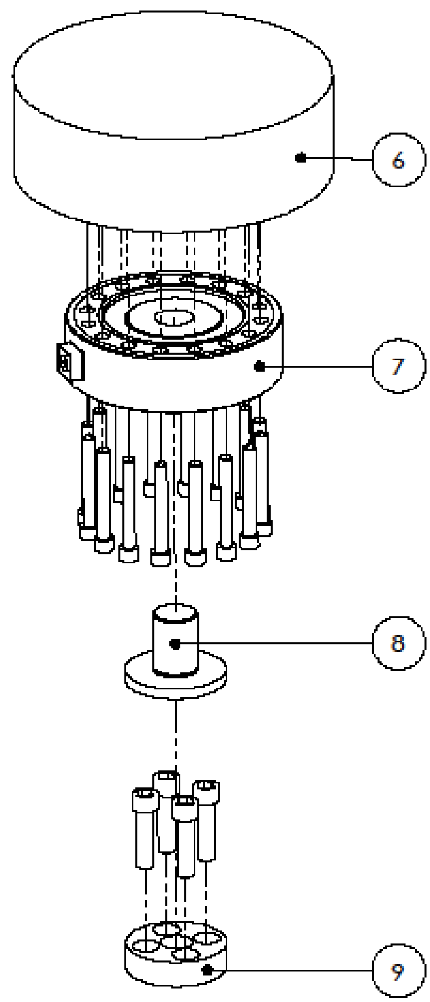
HBM

NEW UPPER ASSEMBLY



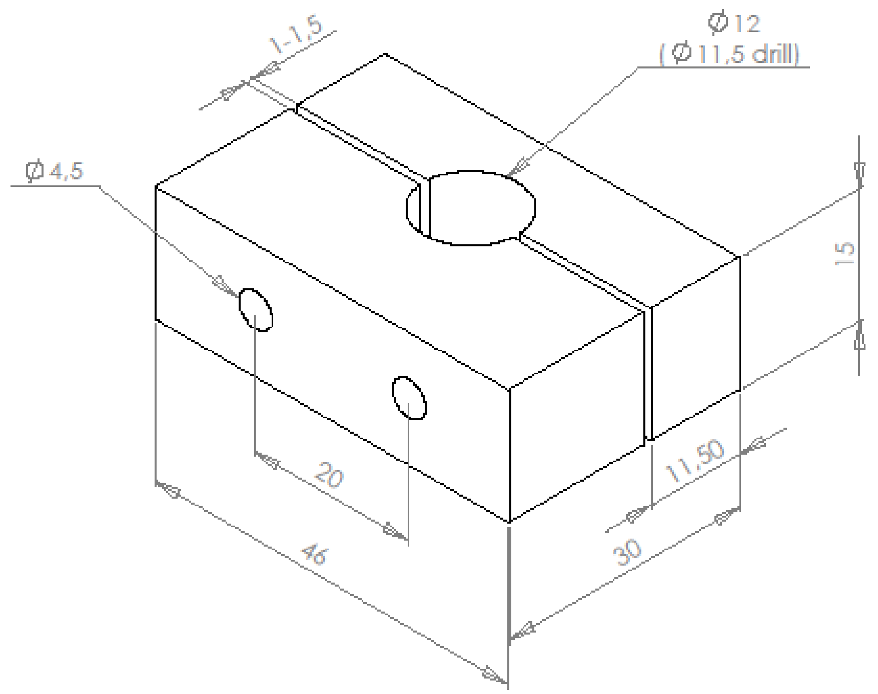
1: Cylinder cushion plate
2: Upper flange
3: Transducer – flange adapter
4: Futek LCF550 load cell
5: Upper push plate

NEW LOWER ASSEMBLY



6: Lower push plate
7: Futek LCF550 load cell
8: Transducer – flange adapter
9: Lower flange

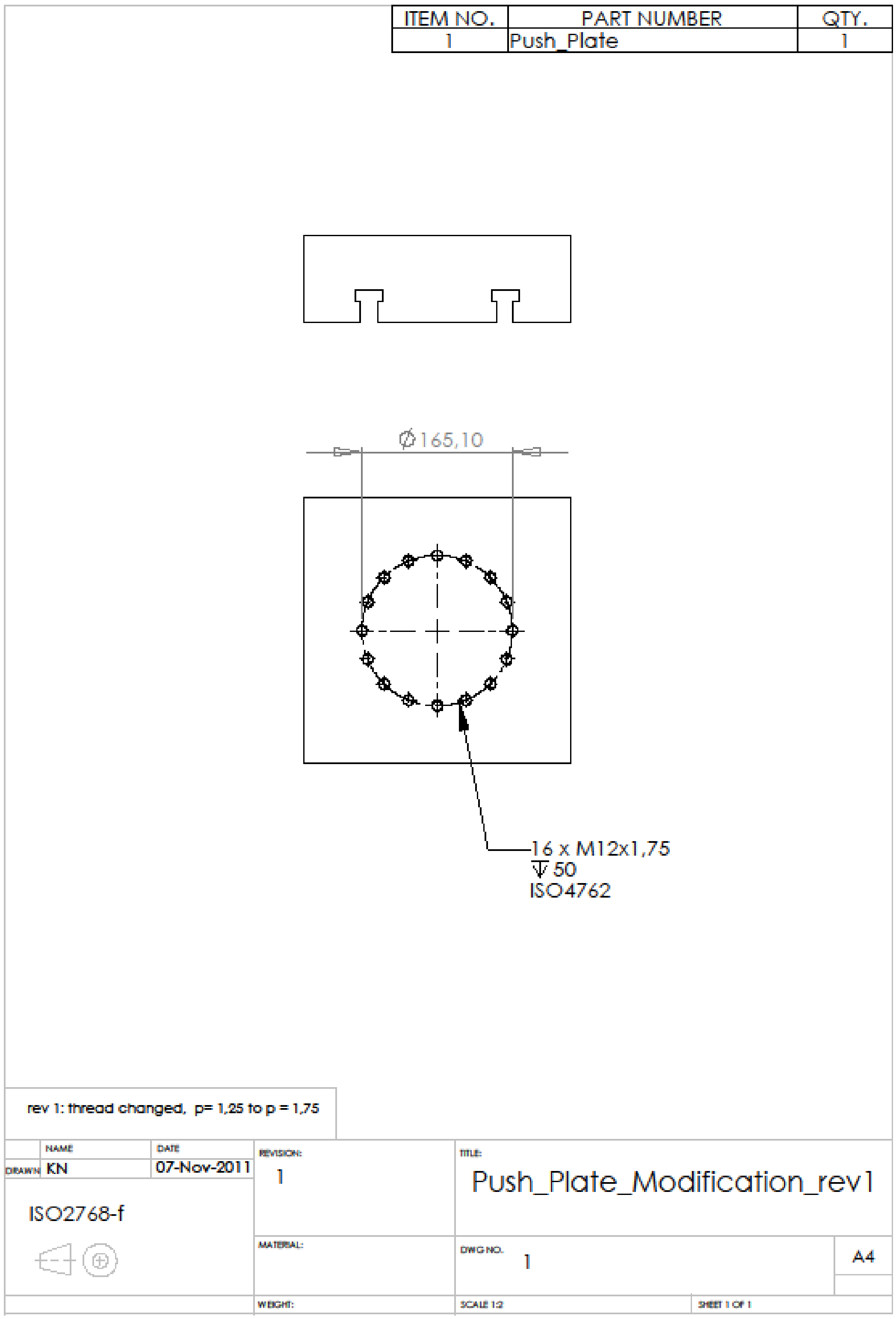
DISPLACEMENT TRANSDUCER MOUNTING BLOCK



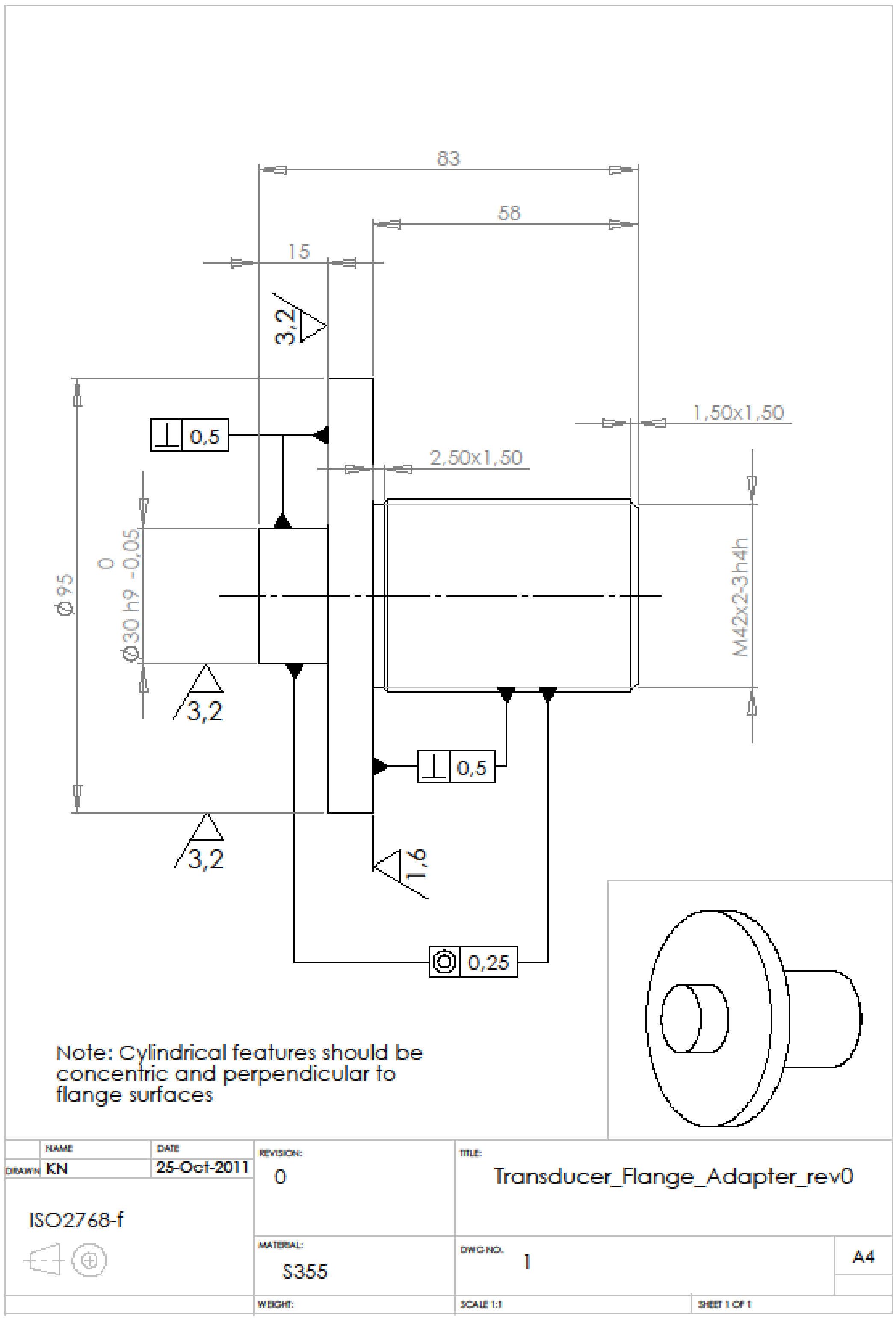
Qty: 2 clamps (2x2 pcs)
Tools required:
drills: Ø4; Ø4,5; Ø11,5
saw: <1,5 blade width
tap: M4 p =0,7
Fasteners required:
4 x M4x40 ISO4014
4 x M4 washer

	NAME	DATE	REVISION:	TITLE:
DRAWN	KN	09-Nov-2011	0	WA_clamp
ISO2768-f			MATERIAL: Nylon	DWG NO. 1 — A4
			WEIGHT:	SCALE 2:1 — SHEET 1 OF 1

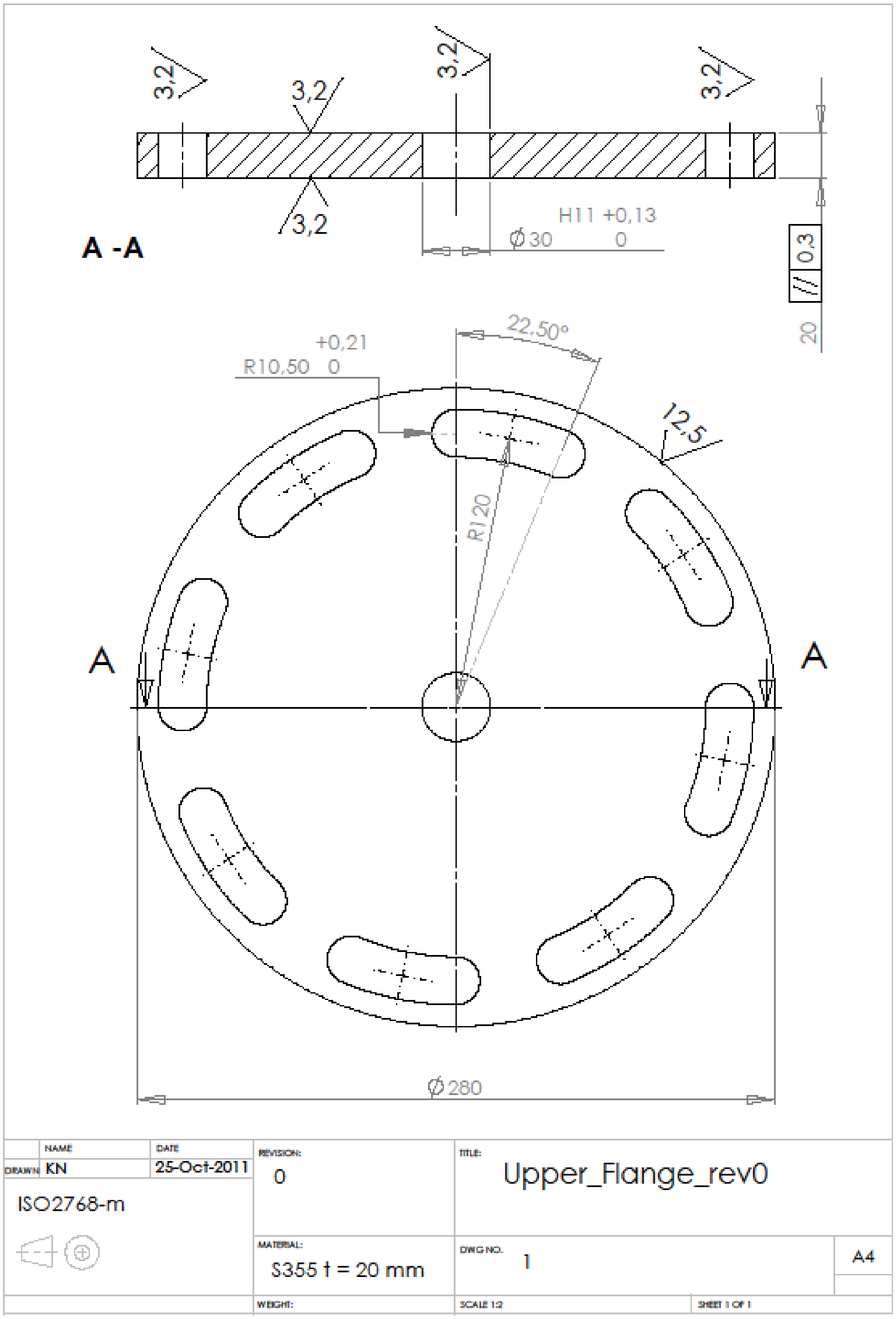
UPPER PUSH PLATE MODIFICATION



TRANSDUCER ADAPTER

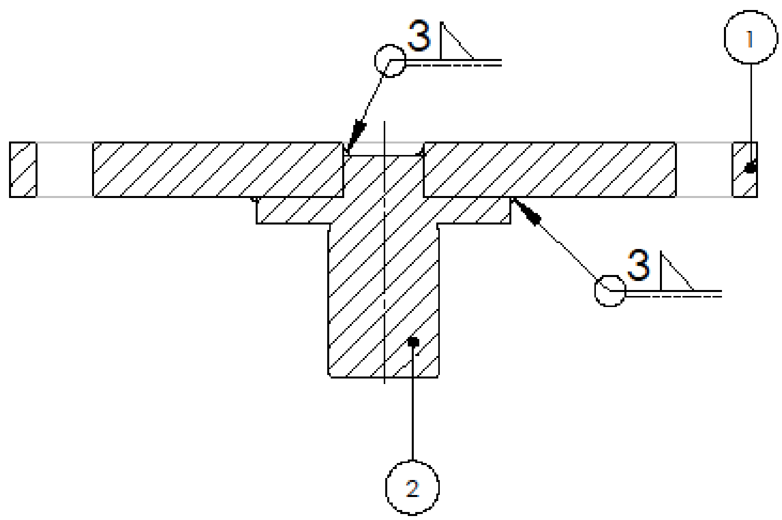


UPPER FLANGE



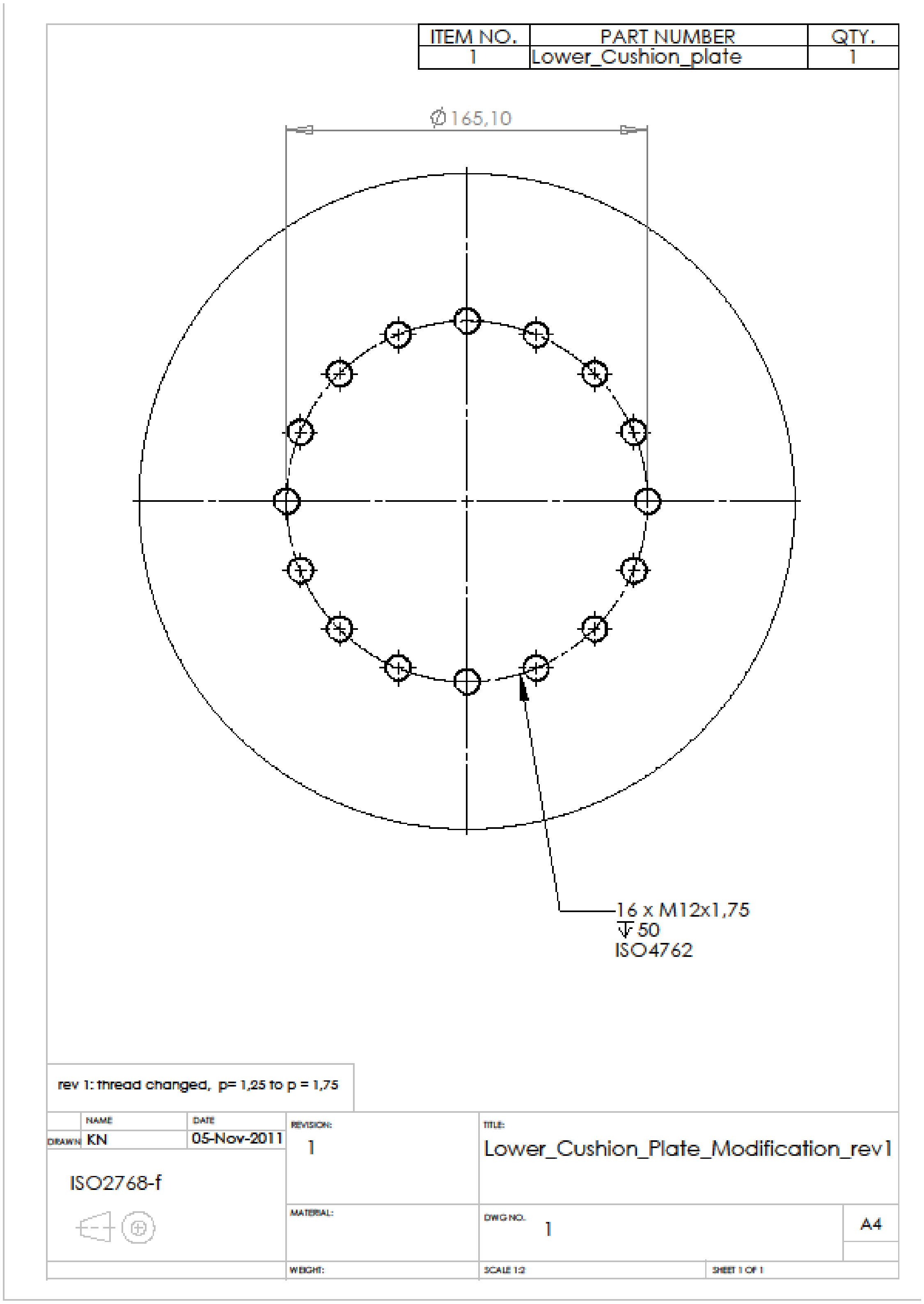
UPPER FLANGE – TRANSDUCER ADAPTER ASSEMBLY

ITEM NO.	PART NUMBER	QTY.
1	Upper_Flange	1
2	Transducer_Flange_Adapter	1

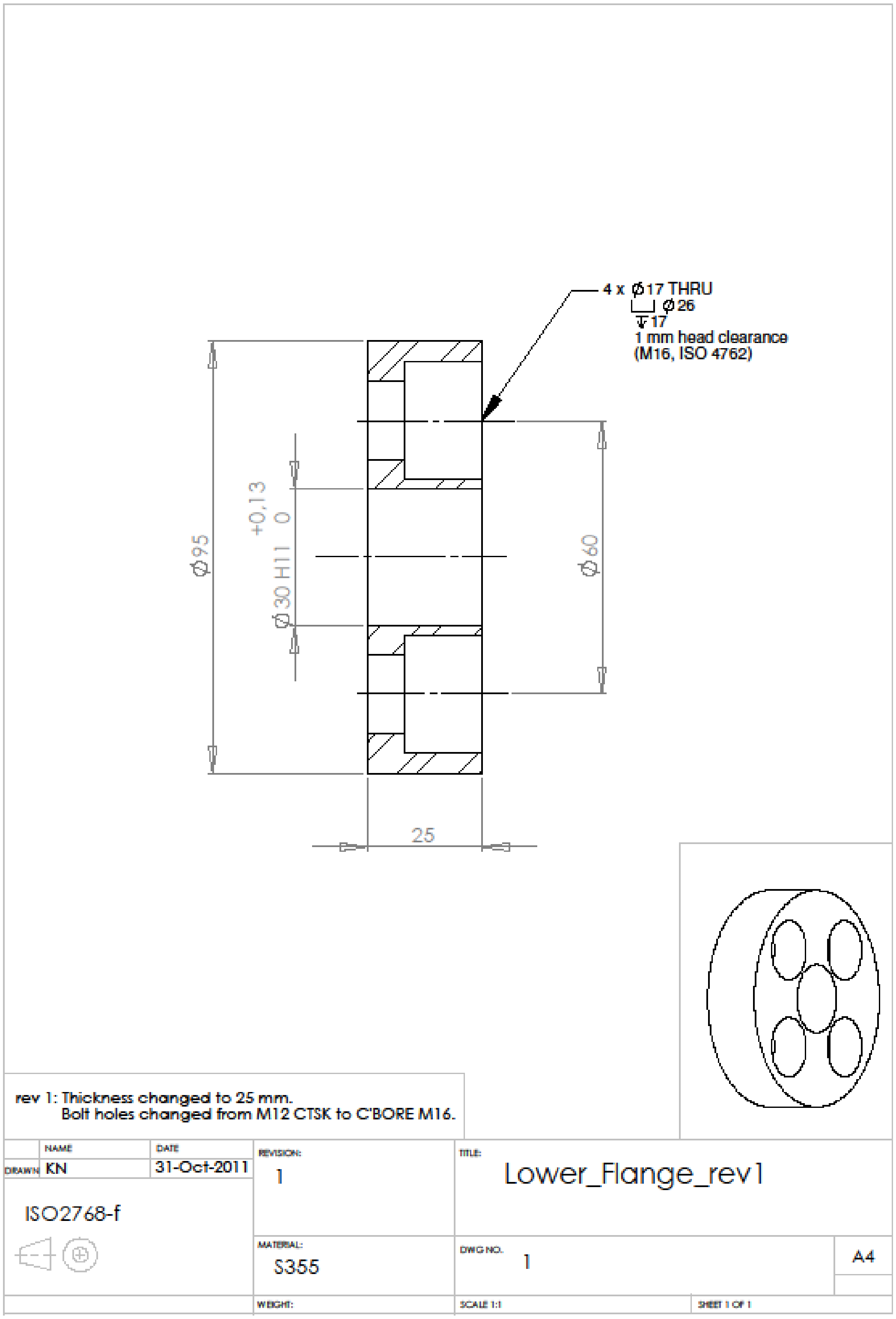


	NAME	DATE	REVISION:	TITLE:
DRAWN	KN	25-Oct-2011	0	Upper_Flange_Assembly_rev0
ISO2768-f			MATERIAL: S355	DWG NO. 1 — A4
			WEIGHT:	SCALE 1:2 — SHEET 1 OF 1

LOWER PUSH PLATE MODIFICATION



LOWER FLANGE



TEST MEASUREMENT SETTINGS

Force 1	Force 2	Displacement 1	Displacement 2
N	N	mm	mm
29.11.11 15:34:52	29.11.11 15:34:52	29.11.11 15:34:52	29.11.11 15:34:52
20.00 ms (50 Hz)	20.00 ms (50 Hz)	20.00 ms (50 Hz)	20.00 ms (50 Hz)
Hardware channel:1 Serial No. (Electronics / CP): 9E50027E6	Hardware channel:2 Serial No. (Electronics / CP): 9E50027E6	Hardware channel:3 Serial No. (Electronics / CP): 9E50027E6	Hardware channel:4 Serial No. (Electronics / CP): 9E50027E6
Sensor: Futek LCF550 1 Sensor T-ID: 1	Sensor: Futek LCF550 2 Sensor T-ID: 2	Sensor: HBM Sensor T-ID: 3300000119735923	Sensor: HBM Sensor T-ID: 0E00000119730723
Amplifier typeMX410	Amplifier typeMX410	Amplifier typeMX410	Amplifier typeMX410
Connector plate: Sub-D Transducer type: SG full bridge	Connector plate: Sub-D Transducer type: SG full bridge	Connector plate: Sub-D Transducer type: Inductive full bridge	Connector plate: Sub-D Transducer type: Inductive full bridge
Measuring range:8 mV/V	Measuring range:8 mV/V	Measuring range:100 mV/V	Measuring range:100 mV/V
Hardware scaling P1:0 ; 0 Hardware scaling P2:-4.0527 ; 444800	Hardware scaling P1:0 ; 0 Hardware scaling P2:-4.08 ; 444800	Hardware scaling P1:0 ; 0 Hardware scaling P2:80 ; 300	Hardware scaling P1:0 ; 0 Hardware scaling P2:80.1 ; 300
Native unit: mV/V	Native unit: mV/V	Native unit: mV/V	Native unit: mV/V
Engineering unit: N Nominal range: -878031.9 N catman Scaling: External hardware	Engineering unit: N Nominal range: -872156.8 N catman Scaling: External hardware	Engineering unit: mm Nominal range: 375 mm catman Scaling: External hardware	Engineering unit: mm Nominal range: 374.5318 mm catman Scaling: External hard-ware
Excitation:2.5 V excitation Filter characteristics: Bessel lowpass	Excitation:2.5 V excitation Filter characteristics: Bessel lowpass	Excitation:2.5 V excitation Filter characteristics: Bessel lowpass	Excitation:2.5 V excitation Filter characteristics: Bessel lowpass
Filter frequency:5 Hz Zero balancing:2387.769 N	Filter frequency:5 Hz Zero balancing:5543.175 N	Filter frequency:5 Hz Zero balancing:137.1273 mm	Filter frequency:5 Hz Zero balancing:119.1082 mm
Tare value:2387.769 N	Tare value:5543.175 N	Tare value:137.1273 mm	Tare value:119.1082 mm
Software zero: 0 N	Software zero: 0 N	Software zero: 0 mm	Software zero: 0 mm
Signal measured: N.A.	Signal measured: N.A.	Signal measured: N.A.	Signal measured: N.A.
Amplifier input: N.A.	Amplifier input: N.A.	Amplifier input: N.A.	Amplifier input: N.A.
Gage factor:0.00000	Gage factor:0.00000	Gage factor:0.00000	Gage factor:0.00000
Bridge factor:0.00000	Bridge factor:0.00000	Bridge factor:0.00000	Bridge factor:0.00000