DESIGN OF A TRANSITION RESISTANCE MEASUREMENT SYSTEM

(According to SFS-EN ISO 18594)

HAMK
UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Mechanical Engineering and Production Technology

Riihimäki, spring 2015

Onome Sotu

DEDICATION

To my mother for her love,

To Henry, Kate, Lee, Viktor, Shongy, Abass, Erezi, Ejiro, Solomon, Oyebanji, Eze and Stanley for being the best people I know.

Riihimäki
Mechanical Engineering and Production Technology
Production Systems

Author Onome Sotu **Year** 2015

Bachelor's thesis Design of a Transition Resistance Measurement System

ABSTRACT

The method described in the SFS-ISO 18594 Standard was implemented to design a transition resistance measurement system. Ohutlevykeskus, a partner of HAMK University of Applied Sciences and specialized in research, development and manufacturing to improve the competitiveness of Finnish sheet metal products, was the commissioning organisation of this thesis work. The transition resistance measurement system would meet the needs of ohutlevykeskus' customers in the quantitative measurement of the surface conditions, as well as determine and ensure an acceptable standard of surface cleanliness of steel and aluminium products.

Limitations in the availability of reference models resulted in the conceptualization of a new and genuine design. The design consisted of a mechanical system which was assembled into a ZWICK/ROEL Z050 tensile test machine. The assembly was made up of a lower and upper structure of identical parts where the sheet whose resistance is measured is placed on a support between the electrodes. The major components of the assembly included the base-parts, electrode adaptor holders and electrodes with a final weight of 20.5kg

The design analysis revealed major bearing stress (up to 8.5MPa) located on the base-parts holding the electrodes. A material selection process, based on the stress calculations, electrical properties, and costs was conducted and nylon 6 (PA6) was selected as the material for the base-parts.

The resistance measurement circuit was designed using the Kelvin resistant measurement technique with the help of either a AEMC 6250 or Megger DLRO 10X micro-ohmmeter.

The designs were accepted as well as the technical documentation and a prototype of the system is being manufactured.

Keywords Transition resistance, measurement, design, spot welding, contact.

Pages 29 p. + appendices 1p.

CONTENTS

1 INTRODUCTION

Contact resistance is a function of the extent to which two surfaces mate intimately or come into contact. It is dependent on the contact size and the state of the surfaces. Since surfaces are quite rough due to the presence of surface films such as oxides, paint, oil and water vapor when examined in a molecular scale, contact only takes place at the highest point

Among the parameters of resistance welding, contact resistance is one of the most critical of the welding connection. At the weld interface, it is considered to be the most influential parameter related to materials. Governed by joule heating, the welding heat generated in resistance welding is proportional to the total resistance of the weldment. Contact resistance varies to a great degree during welding, and it is the main component of the total resistance in a large part of the weld time. It is therefore valuable to have an insight into the dynamics of contact resistance (Parameters in resistance welding n.d.).

The commissioning organization for this thesis work (Ohutlevykeskus) has conceptualized the possibility of utilizing the contact resistance between metallic surfaces and material structure as a quantitative measure of surface conditions, to determine and ensure an acceptable standard of surface cleanliness and as a helpful means of evaluating the effectiveness of cleaning operations carried out on steel and aluminum products.

Though the contact resistances during resistance welding are not directly accessible to measurement (SFS-ISO 18594:2007, 2), it is possible to measure transition resistance. Despite numerous studies, most of which have been experimental, carried out by researchers, research institutes and international standard organizations on contact and transition resistance, there have not been many systems designed to determine or measure the transition resistance for aluminum or steel materials.

The objective of this thesis work was to design a simple system for determining the transition resistance on aluminum and steel by applying the resistance spot-, (projection- and seam) method as described by the Finnish Standards Association SFS-EN ISO 18594 and to build concrete testing equipment. This required manufacturing design drawings. The manufacturability will be tested using SME subcontractors. Presented in this report is the concept of resistance welding, the main design concept, the design solutions and justifications, the necessary stress calculations, appended technical documentation, the standards utilized and recommendations for future work.

Effort was made to ensure that the ISO guidelines were followed as strictly as possible for best results and to ensure a system resembling resistance welding.

2 BACKGROUND

In resistance welding, heat and pressure are combined to induce coalescence. Electrodes are placed in contact with the material, and electrical resistance heating is used to raise the temperature of the work pieces and the interface between them. The same electrodes that supply the current also apply the pressure, which is usually varied throughout the welding cycle. A certain amount of pressure is applied initially to hold the work pieces in contact and thereby control the electrical resistance at the interface. When the proper temperature has been attained, the pressure is increased to induce coalescence. Melting of the base metal does not occur in many resistance-welding operations (Black & Kohser 2008).

A current is passed through the electrodes which incorporate a very low resistance in the circuit and the resistances at the joints of the metals are very high. Thus maximum heating is produced at the point of contact where the weld is made. Generally, alternating current is used and the voltage is stepped down to about 4 - 12 volts by a transformer in order to have high amperage and a good heating effect. The pressure necessary to effect the weld varies from 25 to 100 N/mm2 (Jain 2007).

In some resistance-welding processes, additional pressure is applied immediately after coalescence to provide a certain amount of forging action. Accompanying the deformation is a certain amount of grain refinement. Additional heating can also be employed after welding to provide tempering and/or stress relief. The required temperature can often be attained, and coalescence can be achieved, in a few seconds or less. Resistance welding, therefore, is a very rapid and economical process, extremely well suited to automated manufacturing. No filler metal is required, and the tight contact between the workpieces excludes air and eliminates the need for fluxes and shielding gases (Black & Kohser 2008).

2.1 Resistance welding processes

There are three types of resistance welding processes. They are as follows; Resistance Spot Welding (RSW), Resistance Seam Welding (RSEW) and Projection Welding.

2.1.1 Resistance spot welding

Resistance spot welding (RSW) is the simplest and most widely used form of resistance welding, providing a fast, economical means of joining overlapping materials that will not require subsequent disassembly (Black and Kohser 2008). Due to its capacity to assemble thin sheets in an efficient and dependable manner, Resistance Spot Welding is the primary method of joining in the automobile industry. In fact, every car has approximately 5000 resistance spot welds (Janota & Neumann 2008). Figure 1 presents a schematic of the process. Overlapped metal sheets are positioned between water-cooled electrodes, which have reduced areas at the tips to produce welds that are usually from 1.5 to 13mm in diameter. The electrodes close on the work, and the controlled cycle of pressure and current is applied to produce a weld at the metal interface. The electrodes are then opened and the work is removed.

A satisfactory weld consist of a nugget coalesced metal formed between the faying surfaces. There should be little indentation of the metal under the electrodes (Black & Kohser 2008).

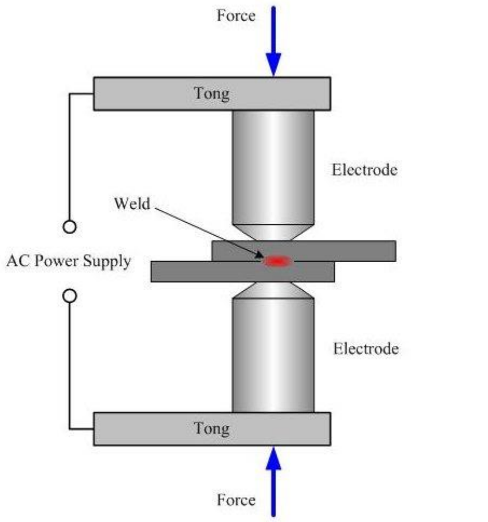


Figure 1 Arrangement of the electrodes and work pieces in resistance spot welding

2.1.2 Resistance seam welding

Resistance Seam welds (RSEW) can be made by two distinctly different processes. In the first process, sheet metal segments are joined to produce gas- or liquid-tight vessels, such as tanks, mufflers, and simple heat exchangers. The welding is made between overlapping sheets of metal, and the seam is simply a series of overlapping spot welds. The basic equipment is the same as for spot welding, except that the electrodes now assume the form of rotating disks, like those shown schematically in Figure 2

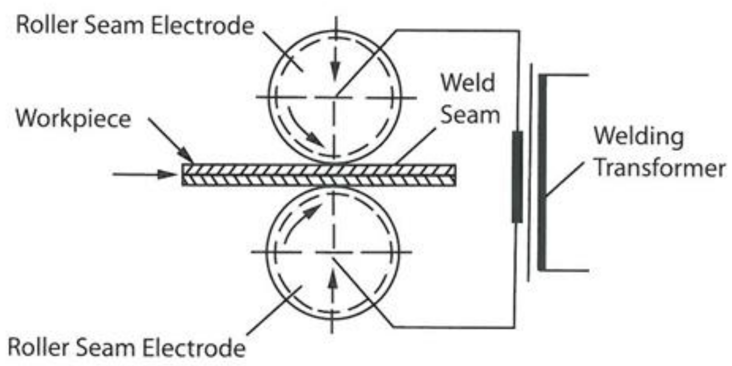
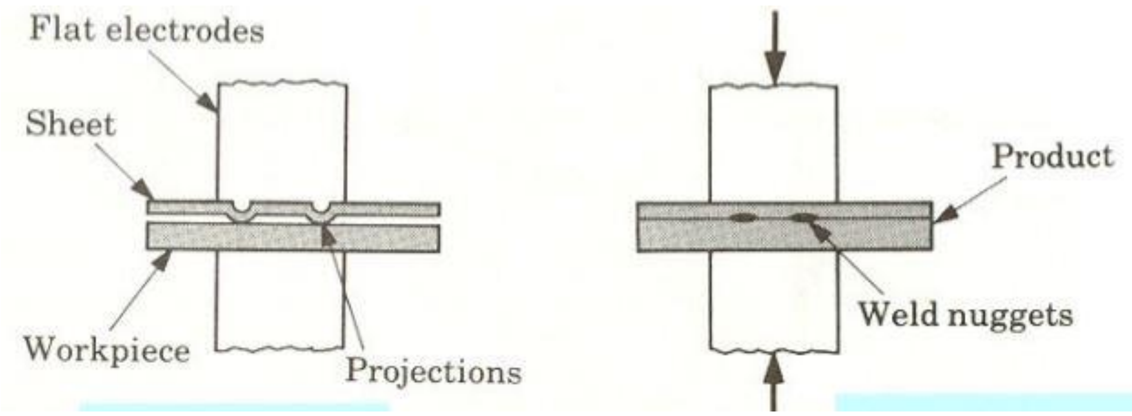


Figure 2 Schematic representation of the seam-welding process

As the metal passes between the electrodes, timed pulses of current form the overlapping welds. The timing of the welds and the movement of the work are controlled to ensure that the welds overlap and the workpieces do not get too hot. The second type of resistance seam welding, known as resistance butt welding, is used to produce butt welds between thicker metal plates. The electrical resistance of abutting metals is still used to generate heat, but a high-frequency current (up to 450kHz) is now employed to restrict the flow of current to the surfaces to be joined and their immediate surroundings. When the abutting surfaces attain the desired temperature, they are pressed together to form a weld (Black & Kosher, 2008).

2.1.3 Projection welding

In mass-production operations, conventional spot welding is plagued by two significant limitations. Because the small electrodes provide both the high currents and the required pressure, the electrodes generally require frequent attention to maintain their geometry. In addition, the process is designed to produce only one spot weld at a time. When increased strength is required, multiple welds are often needed, and this means multiple operations. Projection welding provides a means of overcoming these limitations.



(a) (b)

Figure 3 Principle of Projection welding (a) prior to application of current and pressure and (b) after formation of welds

Figure 3 illustrates the principle of projection welding. A dimple is embossed into one of the workpieces at the location where the weld is desired. The two workpieces are then placed between large-area electrodes in a press machine, and pressure and current are applied just as with spot welding. Since the current must flow through the points of contact (i.e., the dimples) the heating is concentrated where the weld is desired. As the metal heats and becomes plastic, the pressure causes the dimple to flatten and form a weld.

2.2 Electrical characteristics of resistance welding

Governed by the principle of Joule heating, the general expression of heat generated in the resistance welding is expressed by

$$Q = I^2Rt \qquad (1)$$

Where Q stands for the heat, I the welding current in amperes, R the resistance of metal being welded and t the time or duration of current flow

For resistance welding, the heat generated at all locations in a weldment, rather than the total heat generated, is more relevant, as heating is not and should not be uniform in the weldment. In addition, the heating rate is more important than the amount of heat, as how fast the heat is applied during welding determines the temperature history and, in turn, the microstructure. This can be easily understood by considering aluminum welding. If the welding current is low, melting may not be possible no matter how long the heating process is, because of the low electrical resistivity of aluminum, and the fact that the heat generated is conducted out quickly through the water-cooled electrodes and the sheets due to the high thermal conductivity of aluminum (Zhang & Senkara 2011).

The total resistance of a sheet stack-up can be attributed to the contributions of the contact resistance at the electrode-sheet interfaces (R2 and R6 in Figure 4), that at the sheet faying interface (R4), and the bulk resistance (R1, R3, R5 and R7). These quantities are usually not constant- contact resistance is a string function of both temperature and pressure, bulk resistance is sensitive to temperature, not pressure.

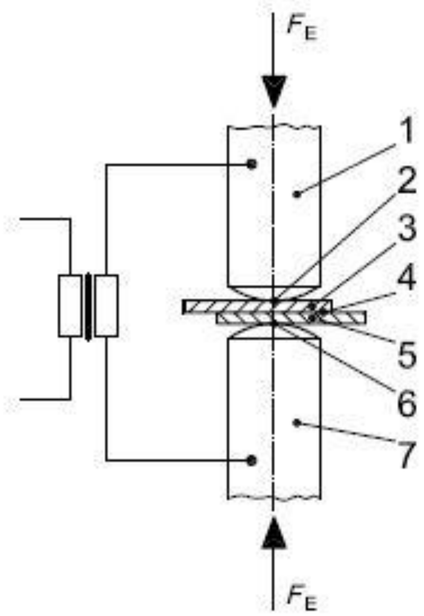


Figure 4 Electrical resistance in a sheet stack-up during RSW (SFS-ISO 18594:2007)

Key
F_E electrode force
1 bulk resistance of top electrode, R3
2 contact resistance top electrode/upper sheet, R2
3 bulk resistance of upper sheet, R3
4 contact resistance sheet/sheet, R4
5 bulk resistance of lower sheet, R5
6 contact resistance lower sheet/bottom electrode, R6
7 bulk resistance of bottom electrode, R7

2.2.1 Bulk resistance

This is the ohmic resistance of an electrical conductor (ISO 18594:2007). It is dependent on the temperature of the metals commonly used in resistance welding as shown in Figure 5. The bulk resistivity of iron (for steels) is very sensitive to temperature, and its value is significantly larger than that of the pure copper. Although copper alloys, such as Cu-Cr-Zr alloys rather than pure copper, are used as electrode materials, the resistivity of pure copper provides an important indication of the relative value of resistivity of the copper alloys compared to the workpieces. The resistivity of copper is significantly lower than that of iron, even at elevated temperatures. Therefore, when an electric current is applied, more heat is generated in the steel sheet stack-up than in the electrodes. This is even more the case as the welding time elapses when the sheets are heated, resulting in higher electrical resistivity in the sheets, as the electrodes are usually water cooled.

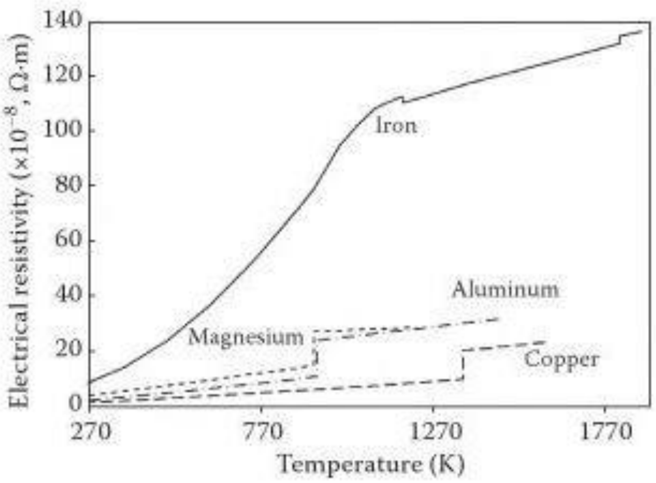


Figure 5 Bulk resistance vs. temperature for Fe, Mg, Al, and Cu (Zhang & Senkara 2011)

Compared with steel, aluminum's electrical resistivity is very low, or its electrical conductivity is very high. In fact, it is very close to copper before it melts as shown in Figure 5. Therefore, it is difficult to weld pure aluminum even when using pure copper electrodes. However, pure aluminum is rarely used in practice. Its various alloys, such as Al-Mg, and Al-Cu are more commonly encountered, and they have significantly higher electrical resistivity than pure aluminum, which makes welding aluminum (alloys) possible. Another important factor in welding aluminum is the usually fairly high surface resistivity from aluminum oxides (Zhang & Senkara 2011).

2.2.2 Contact resistance

Contact resistance is the electric property of a contact area between two bodies. It opposes and limits the passage through it of a steady current (SFS-ISO 18594:2007). Although the bulk resistivity for most metals can be considered independent of pressure, contact resistance is usually very sensitive to pressure distribution, in addition to the surface conditions at the contact interfaces. The apparent contact area at the faying interface is slightly larger than that at the electrode –sheet interface. In general, only a small portion of the apparent contact area is in actual contact, which is formed by irregularities in the form of crests and troughs between the contacting surfaces. During resistance spot welding (RSW), the pressure at the interfaces created by electrodes squeezing smashes the irregularities and causes a decrease in the contact resistance. A small electrode force may not be able to create sufficient electrical contact at the interfaces and may produce concentrated heating and possibly localized melting or even vaporization.

Contact resistance is affected by the surface condition of the sheets. The presence of oil, dirt, oxides, scales, paints and any other foreign content causes a change in the resistance. For bare steels, the surface is usually contaminated by oil/grease, possibly rust etc. Their effect on contact resistance diminishes quickly after an electrode force is applied, especially after the interface is heated by an electric current application. Therefore contact resistance is usually not a concern when welding bare steels.
Coatings deliberately introduced for corrosion protection and other purposes, on the other hand, may significantly affect contact resistance (Zhang & Senkara 2011).

2.2.3 Total resistance

In RSW, the total heat is determined by the total electrical resistance R of the sheet stack-up between the electrodes, which is the sum of individual resistances (contact and bulk resistance) at various locations. Therefore, a change in the total resistances reflects the changes in individual resistance values that are induced by the underlining physical process during welding. Figure 6 shows a comparison of total resistance changes during welding for steel and aluminum alloys.

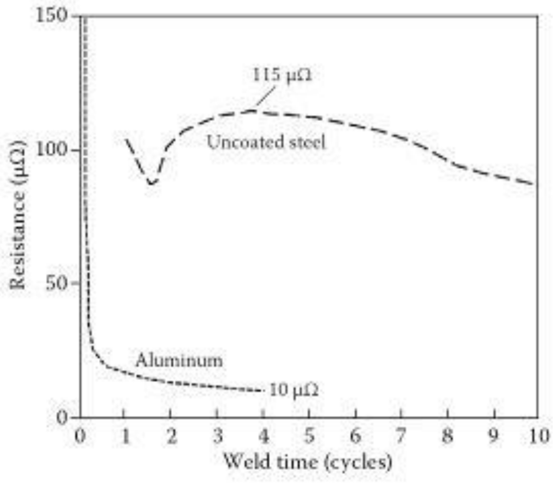


Figure 6 Dynamic resistance for welding a steel and aluminium alloy (Zhang & Senkara 2011)

For aluminium, the presence of Al2O3 on the surface makes the total resistance very high at the beginning. There is a step drop once welding current is applied, implying that the alumina layer is broken under the electrode force and heat. After the initial decrease, the resistance continues to decline, but at a much slower pace.

Because of differences in electrical and mechanical properties, the electrical resistance characteristics of welding are quite different for uncoated steel and aluminium. There is also a drop in total resistance during steel welding, as in welding aluminium, but at a much slower pace, at the beginning of welding. This decrease can be attributed to the changes in contact resistance through burning surfaces agents such as grease. Then an increase in resistance value is observed when welding continues. This corresponds to the rise of bulk resistivity when steel is heated (Zhang & Senkara 2011).

3 DESIGN CONCEPT

3.1 General requirements

The design ideas generated for the transition resistance measurement system was based on the test requirements and setup conditions as described by SFS-ISO 18594:2007(E). These requirements are shown in table 1.

Table 1 Test equipment and setup conditions (ISO 18594:2007)

Measuring and testing equipment	Aluminium	Steel
Force-generating system		
— set-up force	5 kN to 7,5 kN[a]	3,5 kN
— maximum error	± 5 %	± 5 %
Electrodes		
— material	CuCrZr or CuCr	CuCrZr or CuCr
— diameter	⩾ 20 mm	⩾ 16 mm
— radius	150 mm to 300 mm[a]	40 mm to 50 mm[a]
d.c. power source[b]		
— set-up current	e.g. 10 A, < 100 A	
— maximum ripple	± 0,5 %	
— maximum error (reading value)	± 1 %	
Digital voltmeter[b]		
— sensitivity	⩽ 1 µV	
— maximum error of display	1,0 % and ± 1 digit	
(Micro-)Ohm meter		
— measuring current	e.g. 10 A, < 100 A	
— sensitivity	⩽ 0,1 µΩ	

[a] Data to be used shall be specified.

[b] The minimum resolution of the combination d.c. power source and digital voltmeter shall be ⩾ 0,1 µΩ.

As shown in Table 1, the major equipment used with this testing method was the force generating system and electrodes. Therein lay a problem as well, because it prompted the need for a mechanical design concept which will successfully incorporate both the force generating system and electrodes to enable a measurement of the transition resistance with the limitations of the test prerequisite in mind. A cost target for this design work was fixed at maximum 600 euros.

This chapter provides a step-by-step documentation on ideas generated and decisions made to accomplish this design work.

3.2 Mechanical requirements

Due to the test requirements, it was mandatory that the mechanical system comprised of two parts- the upper and the lower parts- attached to respective jaws of the tensile testing machine. The testing mechanism was designed so that tests can be made irrespective of the tensile test machine used.

3.2.1 Force-generating system

The force-generating system acts as the parent structure. As mentioned earlier, the measuring system is incorporated into this parent structure. Due to the high set-up force required for testing (Up to 7.5kN) and the degree of accuracy, it was considered more convenient and less problematic to take into use a pre-existing force system rather than designing one.
The first consideration was the spot welding machine. While this presented a most similar test condition to what was necessary, it failed to meet the test and equipment conditions. Though its accuracy was close enough, it could not generate the required set-up force, thus, ruling out the use of the spot welding machine.

The tensile testing machine was used as the force-generating system. It could provide compressive forces which were needed for testing. The one available at the commissioning organisation (ZWICK/ROEL Z050) could generate forces up to 50kN, accuracy values between 0.5 -1.0% and a very high stiffness which minimised a sliding of the electrode working faces.

Another important addition to the reason for its implementation was the availability of universal adaptors which acted as a link between the tensile testing machine and the measuring system. These adaptors will be discussed further subsequently.

Figure 7 ZWICK/ROEL Z050 tensile testing machine at Ohutlevykeskus

3.2.2 Electrodes

The Chromium Copper (CuCr) or Chromium-Zirconium Copper (CuCrZr) was the required test electrode. Based on their material composition they are classified as group A and type 2, with number designation ranging from 1 – 3 depending on the percentage composition of the alloying elements.
Group A: refers to electrode materials of copper and copper alloys

Type 2: alloys which are harder than the type 1 and in which the mechanical properties have been developed by heat treatment during manufacture or by a combination of heat treatment and cold working

Number 1: CuCr1 (Cr 0.3 to 1.2)

Number 2: CuCr1Zr (Cr 0.5 to 1.4, Zr 0.02 to 0.2)

Number 3: CuCrZr (Cr 0.5 to 1.4, Zr 0.02 to 0.15)

These electrodes are suitable for welding mild steel, coated steel, advanced high strength steel, nickel alloys, aluminium alloys, brass and bronzes (SFS-ISO 5182:2008 (E), 1-6)

The electrodes used are made up of two parts.

- Electrode cap (SFS-ISO 5821:2009(E))
- Electrode adaptor (SFS-ISO 5183-1:2000(E))

Both of the aforementioned are standardized as shown above and are available commercially depending on the dimensions or application.

The chosen electrode cap for this work is marked with full designation and material used as follows:

ISO 5821-A0-19-22-50-A2/1

The above marking designates a spot welding electrode cap type A0 (i.e. taper 1:10), width d_1 = 19mm, length l_1 = 22mm, Spherical radius R_1 = 50mm, and material type A2/1

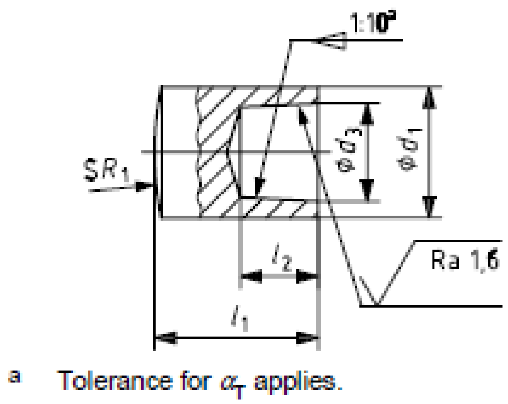


Figure 8 Female electrode caps (SFS-ISO 5821:2009(E), 4)

The chosen electrode adaptor was a male taper 1:10 and marked as shown below:

ISO 5183-1-A-16 X 56-A2/1

This designates a type A welding electrode adaptor of diameter d_1 = 16mm, length l_1 = 56mm and material type A2/1

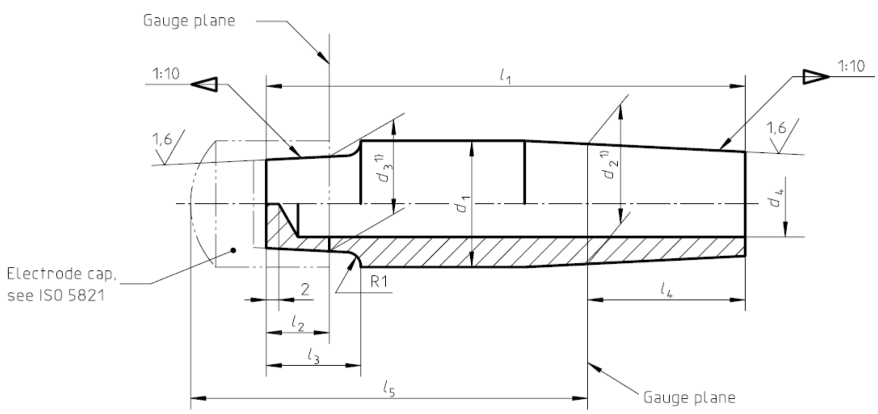


Figure 9 Type A adaptor with cooling hole at one side (SFS-ISO 5183-1:1998(E))

3.3 Assembly parts

The electrodes and tensile test machine while being important cannot be utilised separately. There was a need to incorporate the electrodes into the machine by a mechanical system and also to provide a suitable and convenient means of testing and taking measurements.
The following parts, mostly duplicates, each for the upper and lower part of the mechanical system, when assembled, made up the transition resistance measurement system:

Table 2 Assembly parts and drawing numbers.

Parts	Drawing numbers
Universal adaptor	0000
Base parts	0001 and 0002
Axial alignment	0008_2 and 0009
Centring rods	0010
Electrode adaptor holder	0005
Sheet support.	0006

Geometric dimensioning and tolerance was used effectively in the parts design. This provided geometric control of the parts' shapes, sizes, orientation and location.

3.3.1 Universal adaptor

This adaptor is a part of the tensile test machine. It is a multipurpose adaptor as illustrated in Figure 10, which is used to attach different jaws to the tensile test machine before a testpiece undergoes tension or compression.

It provides the best medium for incorporating the assembly into the force generating system.

Figure 10 ZWICK/ROEL Z050 tensile testing machine universal adaptor.

Two adaptors were required for this system: one attached to the upper jaw and the other one to the lower jaw. They were attached to the tensile test machine by a centre hole and clamped tightly and firmly by a perpendicular bolt through the side holes.

The base parts were attached to these adaptors by the eight holes on the shoulder of the adapter using appropriate screws.

3.3.2 Base parts

Just like the universal adaptors, two pieces of base-parts were needed and each was attached to one adaptor separately. Both parts were similar except for the lower part which had 4 threaded holes on each side. Due to the ease and low cost of manufacture, the base parts were cube shaped (90mm*50mm). This shape provided a good base for implementing support features.

The base is a very important part of the measuring system because it performs two functions

- The material used in the manufacturing of this part was Nylon 6 (PA6).
  Firstly, being a polymer, it was not an electrical conductor, thus it helped to effectively insulate the measuring environment by forming a closed loop during testing when current was passed through the circuit.
  Secondly, it possessed sufficient tensile strength to withstand the compressive force it would be subjected to during testing.
- It served as a fit for the electrode adaptor holder. This fit was a M24 threaded hole and the electrode adaptor holder is threaded in.

The lower base-part which is shown in Figure 11, also served as a means by which a support-for the sheet metal-could be attached to the system. This attachment was made by the means of four threaded holes on two opposite sides of the base.

A special feature of this part, which was also consistent for the other parts, during design and manufacturing, was the removal of sharp edges by chamfering.

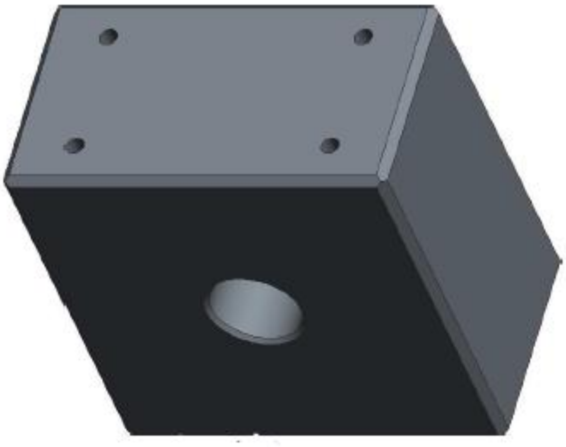


Figure 11 Lower base part showing M5 holes for sheet support and M24 hole for electrode adaptor holder

3.3.3 Axial alignment

One very important feature of the mechanical system was that the eccentricity of the electrode axis should not exceed 0.1mm (SFS-ISO 18594:2007, 6). The purpose of the axial alignment parts as shown in Figure 12 was to ensure that this requirement was met.

It was designed as two replica flat cuboids (250mm*100mm*20mm), with structural steel S355J2 material. Located at the centre was a ring of threaded M5 holes, with the holes and the ring having the same diameter as the universal adaptor. Towards the edges, there were four larger equidistant holes of equal diameter.

The aforementioned four holes were threaded into one of the replicas, while the other replica was not threaded. This was the only difference between the two parts.

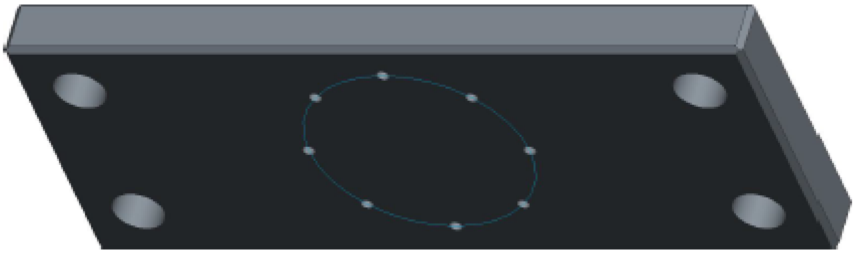


Figure 12 Axial alignment part showing ring of M5 holes and M20/Φ20 holes

To serve its purpose, the axial alignment parts were fitted between the universal adaptor and the base part. The non-threaded part was fixed to the upper part of the mechanical system while the threaded part was attached into the same position but to the lower part of the system. In addition to the centring rods, the axial alignment parts helped keep the electrode axis very concentric.

The principle of how this was achieved is discussed subsequently in this thesis.

3.3.4 Centring rods

The centring rods were four slender rods 30mm in diameter and 350mm long made of S355J2. Each rod was threaded at one end to a length of 18mm, while it was important that the other end was machined to a surface roughness of 1.8 for about 100mm.

The centring rods were threaded into the axial alignment part attached to the lower part of the mechanical system as shown in Figure 13. As mechanical force was applied downwards, the upper part of the system lowered and the electrodes came in contact with the sheet, the rods slid into the upper axial alignment part.

Hence both the centring rods and axial alignment parts worked in tandem to keep the axis of the electrodes concentric. An eccentric axis would have been identified if the rods had failed to slide into the axial parts

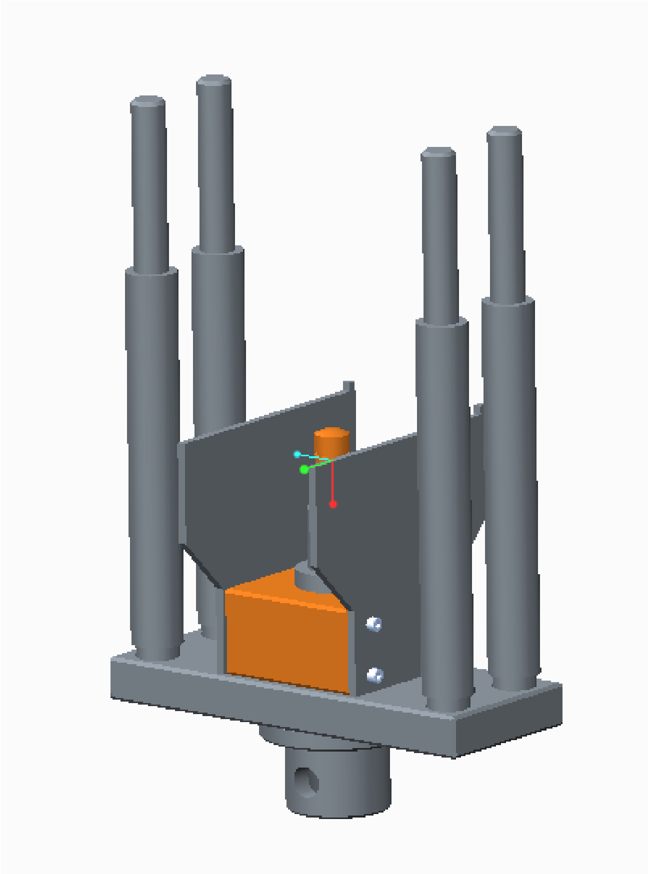


Figure 13 Lower assembly of mechanical system showing the position of the centring rods and sheet support.

3.3.5 Electrode adaptor holder

The electrode adaptor holder provided a fit for the CuCr electrode adaptor. A short shaft 65mm long, one end comprised of a M24 thread 20mm long, while the other end was a tapered extrusion of ratio 1:10

The threaded end of the holder was attached to the base parts while the electrode adaptor fit into the taper because they had similar dimensions. The material was structural steel S355J2.

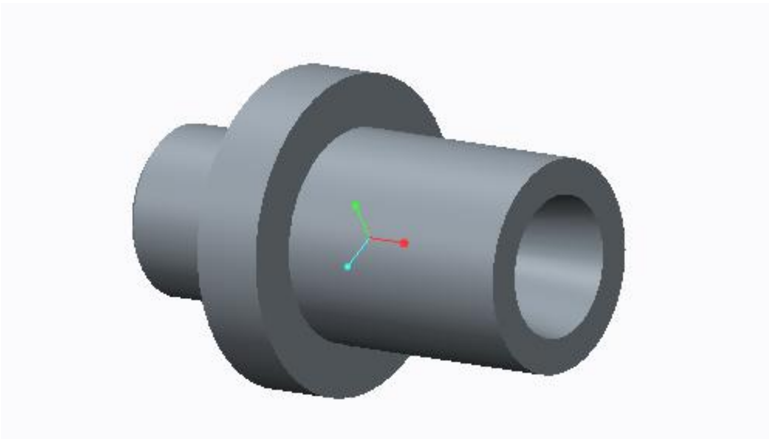


Figure 14 Electrode adaptor holder

3.3.6 Sheet support

As shown in Figure 13, the sheet supports were external features which served as a seat for the sheet metal testpiece during measurement of the transition resistance.

They were assembled into the mechanical system, utilizing the symmetricity of the system, by being screwed into the two replica pieces onto the four M5 holes on both sides of the base parts as described in chapter 3.2.2 with a tightening torque of about 5Nm. It was important that the material composition was an insulator which would help in isolation of current during testing. To meet this requirement, PA6, which was of the same material for the base parts, was the material used in manufacturing of the sheet supports.

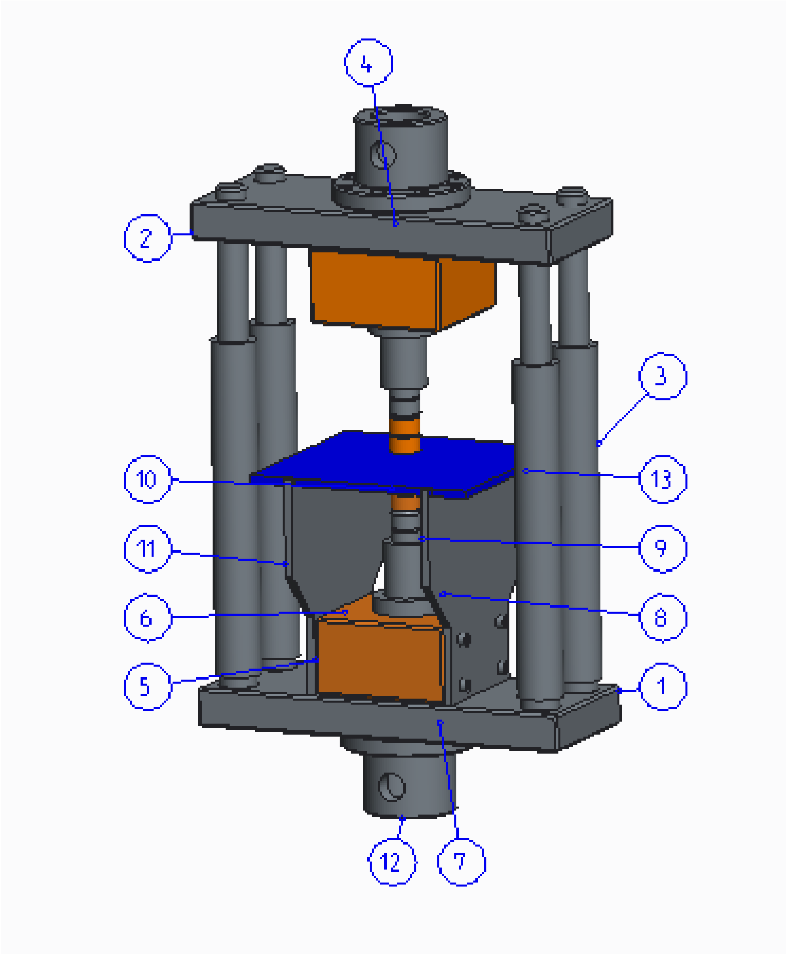
3.4 Final assembly

Shown in Figure 15, is the final assembled structure of the mechanical system. Designed for assembly and manufacturing, it was ensured that the materials were assembled to a high degree of accuracy. The total weight of the system was approximately 20.5kg

Where screws were needed, a standard hex socket head screw (DIN912) was consistently used to ensure easy assembly. The structure was in a working condition, thus depicting the parts in similar condition.

One important feature to be noticed here was the position of the centring rods inside the upper axial alignment part.

The thickness of the sheets is described by the SFS-ISO 18594 standard.



Osa Part	Descript Nimitys	Additional Description Kuvaus	Tunnus Identification	Koko Size	Massa Kg Mass Kg	Kpl Pcs
13	TEST PIECE		0007		0.884	1
12	SUPPORTS BASE PART	ADAPTOR FOR OF TENSILE TEST MACHINE	0000		1.011	2
11	STAND SUPPORT	SUPPORT TESTPIECE	0006		0.098	2
10	ISO 5821-A0-20-22-50-A2/1	SPOT WELDING ELECTRODE CAP	0003		0.046	2
9	ISO 5183-1-A-20x63-A2/1	SPOT WELDING ELECTRODE ADAPTER	0004		0.111	2
8	HOLDS ADAPTORS		0005		0.348	2
7	Hex socket head screw DIN912 - 8.8 -	M5x40			0.007	16
6	Hex socket head screw DIN912 - 8.8 -	M5x16			0.004	8
5	FOR ELECTRODE ADAPTOR HOLDER	ATTACHED TO ADAPTOR	0002		0.435	1
4	FOR ELECTRODE ADAPTOR HOLDER	ATTACHED TO ADAPTOR	0001		0.438	1
3	CHECKS ELECTRODE CENTERING		0010		1.538	4
2	AXIS ALIGNMENT 2	ENSURES ELECTRODES ARE CENTERED	0009		4.621	1
1	AXIS ALIGNMENT	ENSURES ELECTRODES ARE CENTERED	0008_2		4.627	1

Figure 15 Final design assembly of mechanical system and part numbering from CREO design platform

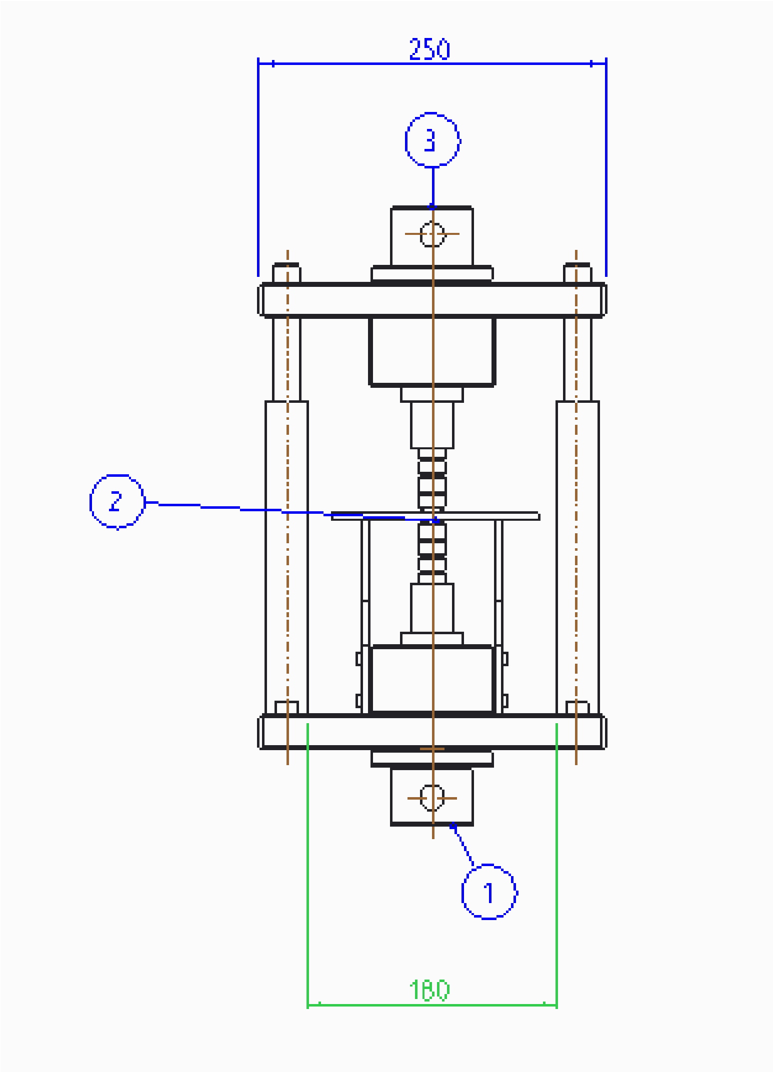


Figure 16   Front view of mechanical system showing functional dimensions

4 DESIGN CALCULATIONS AND MATERIAL SELECTION

4.1 Calculations

The measurement system would be subjected to compressive forces up to 7.5kN during resistance measurements. Therefore it was important to design the system to overcome the stresses created by the size and nature of the load. The weakest point most susceptible to failure was the threaded joint between the base parts and the electrode adaptor holder as shown in Figure 17

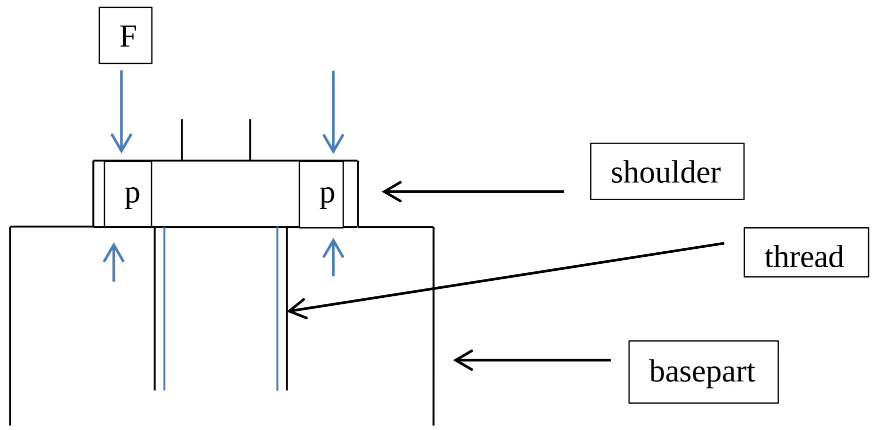


Figure 17 Schematic of threaded joint most susceptible to failure

When a nut engages a thread, theoretically all the threads in engagement should share the load. In actuality, inaccuracies in thread spacing cause virtually all the load to be taken by the first pair of threads. Thus, the conservative approach in calculating thread stresses is to assume the worst case of one thread-pair taking the entire load. The other extreme is to assume that all the engaged thread share the load equally.
Both of these assumptions can be used to calculate estimated thread stresses. The true stress will be between these extremes, but most likely closer to the one-thread assumption (Norton 2011).
The base parts were made of a softer material (PA6) which is weaker than the material of the electrode adaptor holder (S355J2). This promotes local yielding in the nut threads when the adaptor holder is tightened, which can improve the thread fit and promote load-sharing between threads. The mechanical system, from mode of application, experiences two kinds of stresses- axial and shear stress.

4.1.1 Shear stress

One possible shear-failure mode involves stripping of the threads either out of the nut or off the screw. Which, if either, of these scenarios occurs is dependent on the relative strengths of the nut and screw material

– If the nut or tap hole material is weaker, it may strip its thread at its major diameter
– If screw is weaker, it may strip it\s thread at it\s minor diameter.
– If both materials are of equal strength, assembly may strip along pitch diameter

In order to calculate stresses, we must assume some degree of load sharing among the threads
Since complete failure requires all threads to strip, all threads can be considered to share the load equally. This is a good approach as long as nut or screw (or both) is ductile, allowing each thread to yield as assembly begins to fail.
If we express the shear area in terms of number of threads in engagement, a judgement can be made in each case as to what degree of load sharing is appropriate (Norton 2011)
The tap material is weaker than the adaptor holder material; therefore the tap will strip as its major diameter.
For the tap striping at its major diameter, the shear area for one screw thread is

$$A_s = \pi d w_o p \qquad (2)$$

Where the value for w_o at the major diameter is given in table 3

Table 3 Area factors for shear stripping shear area (Norton 2011)

Thread Type	**w_i (minor)**	**w_o(major)**
UNS/ISO	0.80	0.88
Square	0.50	0.50
Acme	0.77	0.63
Buttress	0.90	0.83

For M24 thread,

major diameter, $d = 24mm$

$w_o = 0.88$

$p =$ thread pitch $= 3mm$

$A_s = \pi \cdot 24mm \cdot 0.88 \cdot 3mm$

$A_s = 199mm^2$

shear stress for thread stripping is given by

$$\tau_x = \frac{F}{A_s} \qquad (3)$$

$$\tau_x = \frac{7500N}{199mm^2} = 37.7MPa$$

$$\tau_{all} = \frac{\text{yield strength of PA6, } R_e}{\text{factor of safety in shear, } \sqrt{3}} = \frac{45MPa}{\sqrt{3}} = 26MPa$$

$\tau_x > \tau_{all}$ Not OK!

From the results of the calculations, the thread will strip and the tap hole material (base part) will shear thus resulting in design failure. To prevent this failure, the adaptor holder design was modified to as described in 4.2.2

4.1.2 Axial stress

The adaptor holder fastened to the base part basically experiences axial tension from the applied load, similar to a threaded fastener. To compensate for this axial load and shear failure as shown from the shear stress analysis, a ‘shoulder’ was introduced in the adaptor holder as shown in Figure 17. This shoulder will take most of the stresses, thus relieving the thread from shear. The regions ‘p’ were under bearing and shear stresses. The axial tension exerted by the load on the system is thus determined:

Axial bearing stress $\delta_{bearing} = \frac{F}{A^{'}}$ (4)

where F, the load on the system = $7500N$

and $A^{'}$ is the area of shoulder on the base part = $\frac{\pi}{4}\left(d_1^2 - d_2^2\right)$

d_1 = outer diameter of the shoulder = $45mm$

d_2 = inner diameter of the shoulder = $30mm$

$$A^{'} = \frac{\pi}{4}\left(45_1^2 - 30_2^2\right)$$

$$A^{'} = 884mm^2$$

$$\delta_{bearing} = \frac{F}{A^{'}} = \frac{7500N}{884mm^2} = 8.5MPa$$

$$\delta_{allowed} = \frac{\text{yield strength of PA6, } R_e}{\text{factor of safety, } n} = \frac{45MPa}{2} = 22.5MPa$$

$$\delta_{bearing} < \delta_{allowed} ......OK!$$

The shear stress was also determined

The shear is given as: $\tau = \frac{F}{A^{''}} \leq \frac{R_e}{\sqrt{3}}$ (5)

$$A^{''} = \pi dt$$

$t =$ shoulder thickness = $10mm$

$d =$ thread diameter = $24mm$

$$A^{''} = \pi \cdot 24mm \cdot 10mm = 754mm^2$$

$$\tau = \frac{F}{A^{''}} \leq \frac{R_e}{\sqrt{3}} = \frac{7500N}{754mm^2} \leq \frac{45}{\sqrt{3}} = 10MPa \leq 26MPa$$

$$\tau = 10MPa \leq 26MPa$$

$\tau_{shear} < \tau_{allowed}$ This is OK!

As shown from the calculations, the axial tension exerted on the system is less than allowed axial tension, thus implying the structure is strong and can handle the axial stress thus relieving thread of the shear stress.
To also improve safety, the length of the tap hole was increased to twice the major diameter of the thread $(2d)$

4.2 Material selection

Unlike major material selection processes, one important factor which contributed to the main material used in this design work was provision of insulation during resistance measurement.
Since a high current from a DC-power source would be transmitted through the system, it was necessary to provide a closed whereby the current is restricted to only the electrodes and sheets thereby preventing short circuiting. As well as providing insulation, the material for the base part should be strong enough to withstand the stresses it would be subjected to during measurement and reasonably priced.

Some possible materials considered, all of which are insulators, were

- Rubber
- Wood
- Nylon
- Polyethylene/Polypropylene
- Carbon or Glass fibre reinforced plastic (CFRP/GFRP)

4.2.1 Selection criteria

Using their yield strength values, cost per unit and mechanical properties, some of the aforementioned materials were eliminated.

- Yield strength

While readily available commercially, and at reasonable prices too, polyethylene and polypropylene with yield strengths around 26 and 12MPa, from the results obtained in the stress calculations, will fail is they are used in the mechanical system. Thus they were eliminated.

- Cost per unit

CFRP and GFRP are ultimate mechanical engineering materials and very desirable in design solutions. They are very exotic, expensive and can cost as high as 30 euros/kg (Bregar 2014) while also proving too strong for this application.

- Mechanical properties

With young modulus as low as $0.01 \cdot 10^9 GPa$ and no yield strength value, rubber was deemed unsuitable for application thus eliminated. Wood on the other hand, seemed quite promising but also eliminated due to its low ultimate tensile strength value corresponding to the needed value from the calculations, low ductility which is unsuitable considering the kind of stresses experienced by the threads and susceptibility to sudden failure.

4.2.2 Nylon 6/6 (PA6)

Nylon 6/6 materials have high mechanical strength and superior resistance to wear and organic chemicals. With high tensile and flexural strength, and acceptable values for ductility and Young’s modulus it was suited for the design work.

Its allowed yield strength value was almost trice more than the stresses in the mechanical system.
At a price of 4 euros/kg (Smouk 2013), it is a lot cheaper compared to the next most suitable materials for this system. The figure below shows some characteristics of Nylon

Table 4 Properties of PA6 (Matbase n.d.)

Chemical properties

	Minimum value	Maximum value	Unit
Solidification shrinkage	0.3	2	%
Water absorption	2	4	%

Electrical properties

	Minimum value	Maximum value	Unit
Breakdown potential	17	35	kV/mm
Dielectric loss factor	0.04	0.06	%
Electrochemical potential			V
Resistivity	1.00E+017	1.00E+020	Ohm.mmÂ²/m

Manufacturing Properties

Mechanical properties

	Minimum value	Maximum value	Unit
Bending strength	110	120	MPa
Compressive strength	46	90	MPa
Creep strength			MPa
Density	1120	1140	kg/mÂ³
Elongation	100	320	%
Fatigue failure	31	31	MPa
Friction coeficient	0.38	0.45	
Impact strength	0.44	3	J/cm
Shear modulus			MPa
Tensile strength	48	85	MPa
Thickness			MPa
Yield strength	35	40	MPa
Young's modulus	2300	2500	MPa

5 METHOD OF RESISTANCE MEASUREMENT

The transition resistance R_t, as mentioned earlier cannot be measured directly. It is the measured as the difference between the total resistance and the set-up resistance

The total resistance R, is the electrical resistance measured between the sensing clamps (includes both bulk and contact resistances) as shown in Figure 18

The setup resistance R_s, is the resistance of the experimental set-up between the sensing clamps without metal sheet(s) between the electrodes, the two electrodes being in direct contact.

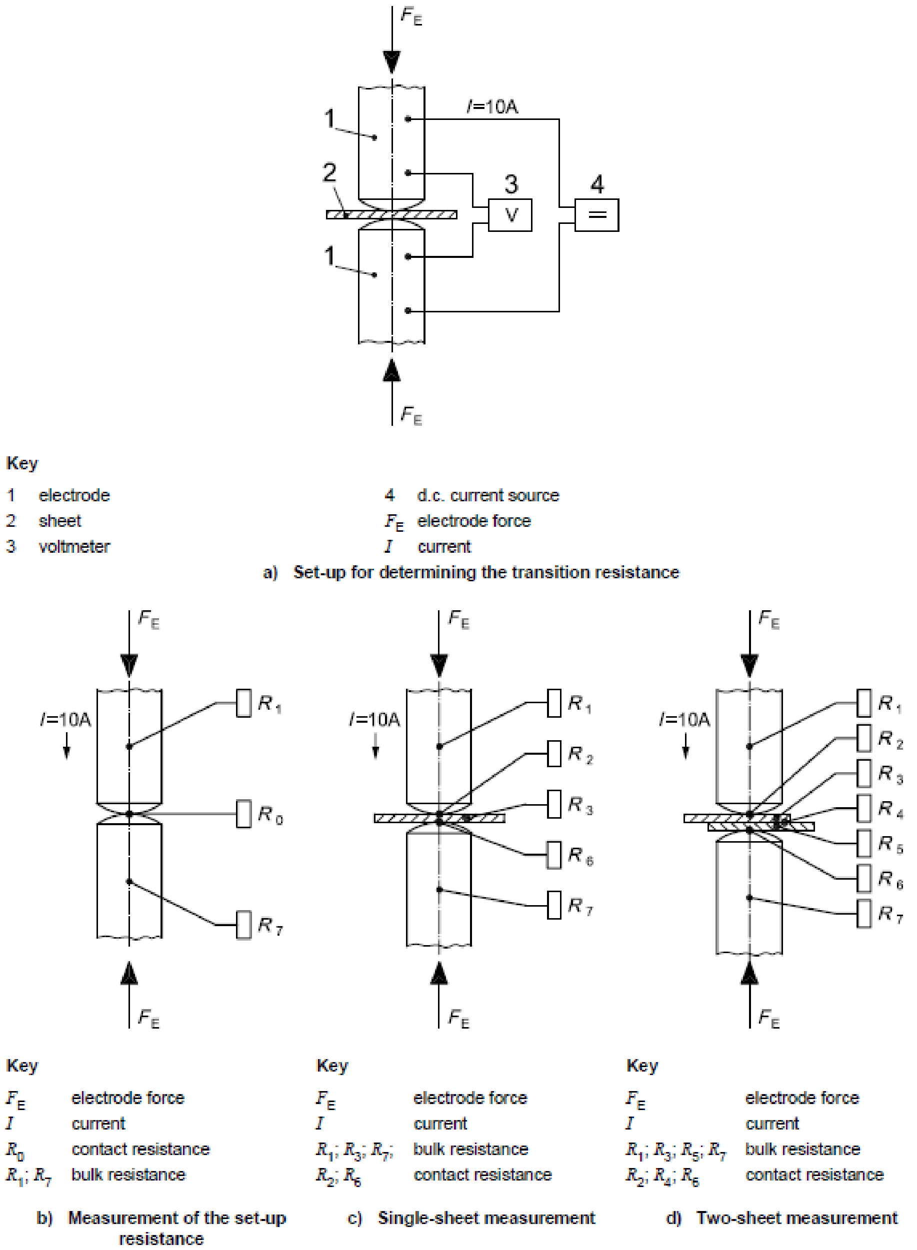


Figure 18 Experimental set-up for determining transition resistance (ISO 18594:2007)

Figure 18a shows the set-up including the connection to a voltmeter and direct current source in a two terminal circuit connection.

5.1 Kelvin resistant measurement

For high precision measurements, the above types of meters are inadequate. This is because the meter's reading is the sum of the resistance of the measuring leads, the contact resistances and the resistances being measured. To reduce this effect, a precision micro-ohmmeter having four terminals, called kelvin contacts is used in a measurement system called the kelvin (four-terminal sensing) resistance measurement.
Kelvin connections are often required in current shunts and current sensors to achieve optimum performance and accuracy. The four-terminal method of measurement eliminates inaccuracy attributable to lead resistance, which can be quite significant in low-value resistors. Furthermore, the use of four-terminal connections avoid the TCR (temperature coefficient of resistance) contribution of the lead wires thereby resulting in tighter thermal stability compared to conventional two-terminal shunts.

Figure 19 Four-terminal connection (developed by Lord Kelvin) showing four connection points. (RCD Components n.d.)

The figure above illustrates the four-terminal connection that enables the voltage drop to be measured across the resistance element itself instead of the element and lead wires. One pair of leads is used for voltage measurement and the other for current sensing. The voltage between E1 and E2 is proportional to the current flow between I1 and I2 and the resistance between junctions “a” and “b”. The voltage circuit has a high impedance so it draws no significant current. With no current through the sense leads, there can be no lead voltage drop, and therefore the lead resistance is eliminated. Furthermore, the TCR of the current leads is eliminated since the voltage connections are generally affixed directly (or very close) to the resistance element. Errors and accuracies attributable to lead resistance, contact resistance, and temperature coefficient are greatly minimized via use of “kelvin” circuits. (RCD Components n.d.)

5.2 Micro-ohmmeter

A micro-ohmmeter provides the best solution in resistance measurement, but to be used in practice, they must meet the test requirements as shown in Table 1.

Two possible micro-ohmmeters that could be employed for this purpose were the AEMC 6250 or the Megger DLRO 10X. Either of these micro-ohmmeters acts as a power source to the circuit and possesses the required accuracy, ripple limits, sensitivity and error limits.

The specifications of each micro-ohmmeter are appended to this thesis work depending on which is used.

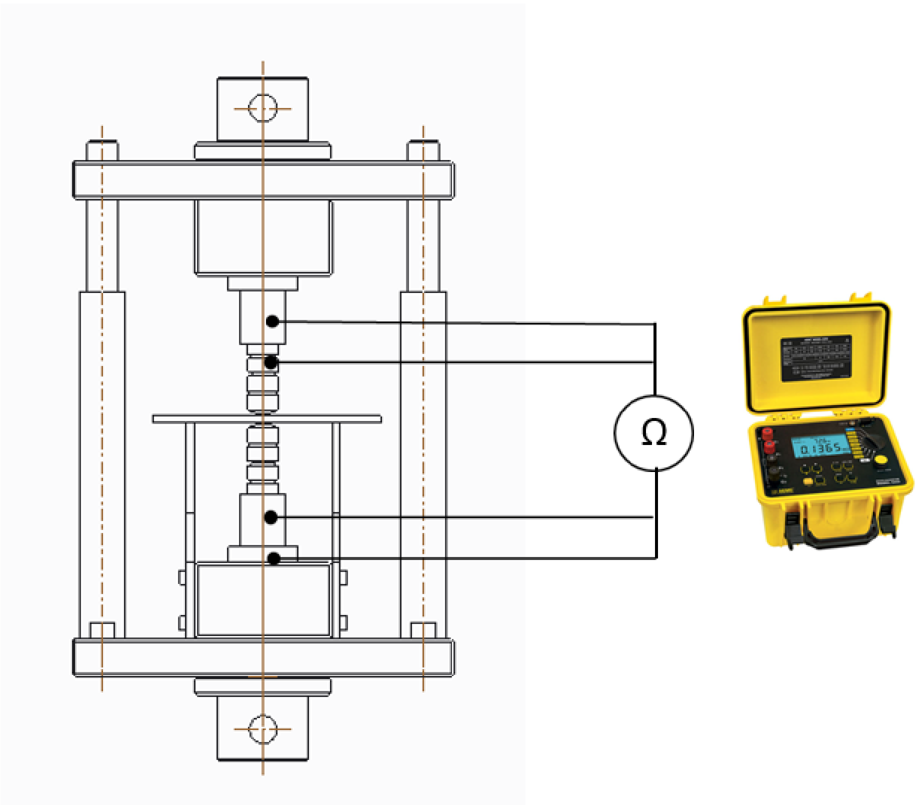


Figure 20 Schematic of the transition resistance measuring system showing four terminal connections.

6 CONCLUSION AND RECOMMENDATIONS

The transition resistance measurement system was designed to specifications based on the SFS-ISO 18594:2007 test guidelines with a high level of measurement accuracy and maximum concentricity without compromising part shape or structure. The parts where designed to allocate for the best possible stress distribution and concentration as well as for manufacturing and assembly.

Using a factor of safety of 2, the yield strength of the materials selected for the system (S355J2 and PA6) were much higher than- and could thus withstand- the compressive and bearing stresses on the mechanical system.

Due to the absence of a reference design sample and with the time constraint, this thesis work provided an interesting challenge and opportunity for the author to apply innovative reasoning, ideas generated and decision making to problem solving here.

The same way it limited the focus to a specific aspect of engineering, it broadened the perspective of a design process, thus ensuring that this work was made with due diligence, advice and support from experienced personnel at Ohutlevykeskus and HAMK.

Even though lots of resources were allocated for this work improvements can still be made here depending on interest, intended usage and financial disposition. Firstly, if the measurement system is to be applied on a regular basis with a low budget, then it would be advisable to change the base part material. This is due to the susceptibility of PA6 to mechanical creep. Another insulating material for example GFRP or CFRP, albeit being expensive, has higher mechanical strength and creep resistance.

On the other hand, with a higher budget and time, a miniature automated testing device as designed by Zwick GmbH & Co. can be purchased and utilised. Another possibility is the use of a gleeble machine. This is more suitable for larger organisations due to the cost but it provides a wide range of possible test simulations and is not just targeted for transition measurement determination.

SOURCES

Black, J.T. & Kohser, R.A. 2008. DeGarmo's Materials and processes in manufacturing. 10th edition. New Jersey: Wiley.

Bregar, B. 2014. 'Price keeping carbon fiber from mass adoption'. Plastic news. Accessed 3rd May 2015. http://www.plasticsnews.com/article/20140805/NEWS/140809971/price-keeping-carbon-fiber-from-mass-adoption

Jain, R.K., 2007. Production technology. 16th edition. Delhi: Khanna

Janota, M. & Neumann, H. 'Share of spot welding and other joining methods in automobile production', Welding in the World, 2008, pdf-file. Accessed 21st March 2015. https://online.tugraz.at/tug_online/voe_main2.getvolltext?pCurrPk=46049

Norton, R.L. 2011. Machine Design: An integrated approach. 4th edition. New Jersey: Pearson

PA 6. Matbase n.d. Accessed 4th May 2015. http://www.matbase.com/material-categories/natural-and-synthetic-polymers/engineering-polymers/material-properties-of-polyamide-6-nylon-6-pa-6.html#properties

Parameters in resistance welding n.d. Swantec. Accessed 20th March 2015. http://www.swantec.com/parameters-in-resistance-welding.php

RCD components n.d. 2-terminal vs. 4-terminal resistors, pdf-file. Accessed 6th May 2015. http://www.rcdcomponents.com/rcd/press/R-31%20Two-Terminal%20vs.%20Four-Terminal%20Resistors.pdf

SFS-ISO 18594:2007(E). Resistance spot-, projection- and seam-welding —Method for determining the transition resistance on aluminium and steel material. Geneva: International Organisation for Standardization.

Smouk, D. 2013. 'Nylon engineering plastics supply plentiful'. My purchase center. Accessed 3rd May 2015. http://www.mypurchasingcenter.com/commodities/commodities-articles/nylon-engineering-plastics-supply-plentiful/

Zhang, H. & Senkara, J. 2011. Resistance Welding: Fundamentals and applications. 2nd edition. London: CRC

Appendix 1

GENERAL THESIS APPENDICES

All appendices are added as hardcopy and available in HAMK Riihimäki unit.

- Technical drawings
- Power-point presentation material
- SFS-ISO 18594 Standard