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Influences of line and contact impedance of the efficiency by non-conventional processes

HERZIG Mathias[1,a*], SCHULZE Hans-Peter[1,b] and KRÖNING Oliver[1,c]

[1]Leukhardt Schaltanlagen Systemtechnik GmbH, Magdeburg, Gustav-Ricker-Straße 62, Germany

[a]mathias.herzig@leukhardt-system.de, [b]hans-peter.schulze@leukhardt-system.de, [c]oliver.kroening@leukhardt-system.de

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Abstract. The basis for an efficient application of the non-conventional processing methods Electric Discharge Machining (EDM), Electrochemical Machining (ECM), or a hybrid ED-EC-processes are the right and stable operating points. Correct matching between source, line and process is necessary for that. In general, the conductivity of transition points can shift the operating point. Especially for pulsed processing ECM and hybrid, the frequency response of the supply configuration is essential. The supply impedance depends on the working frequency, the electrical conductivity, and the capacity of the working medium used. The following examination should analyze which influences, in particular, have the supply lines and the contacts on the process. Using an experimental test setup, the contacts under various forces, frequencies, materials and surface scratches. Fundamentals of contact impedance measurements, surface film, and roughness are discussed, as well as the influence of impedance on an operating point. Especially for ECM, the intention to strike a particular operating point must consider the used medium's nonlinear characteristic line. The results are significant in building experimental testing facilities and changing industrial systems for special inserts. By analyzing the impedances, particularly the process energy source used, to avoid misinterpretations regarding process control.

Introduction

The system technologies of non-conventional processing methods are mostly machines geared towards the application process. This means that the impedances of sources and connection configuration must also be adapted to the application. For test systems knowing the impedances and being transparent about their relationships is necessary. Otherwise, questions related to the process configuration are impossible, or the interpretation of the results is impossible. Another source of error is that the system technology is changed. After the change, the integrated measurement and control technology incorrectly interprets the process state and reacts accordingly. A simple example of this is extended connecting cables. Fig. 1 shows the relationships between the essential sections influencing the overall impedance and, thus, the real effect of the PES pulses on the working gap. Block S is the process energy source with its internal resistance, which can be a voltage source, a current source or a hybrid source. Block P represents the variable resistance of the EC process, although the double layers as a parallel connection of resistance and capacitance are not considered here.

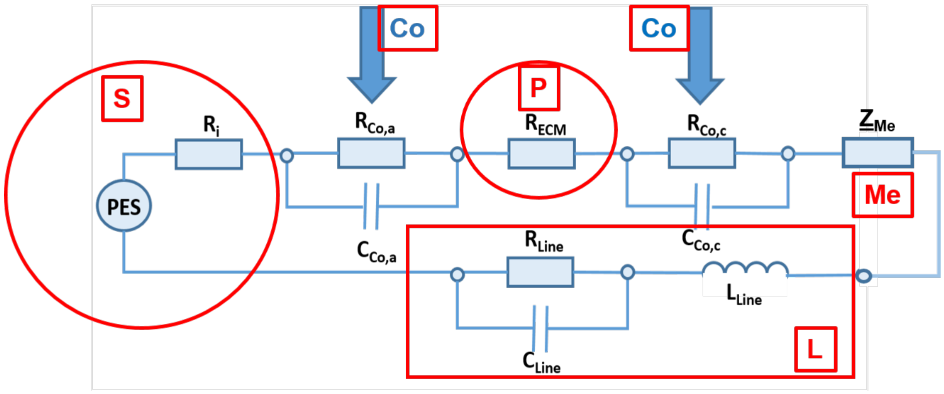

Fig. 1: Equivalent circuit for ECM machine

Block Me is an active influence by a measuring sensor, for example, a measuring shunt for current measurement. Their structure determines the impedance of the supply line and its components, as connecting cables are often used as double wires. Coaxial and braided cables are also conceivable. For AC or pulsed applications, the weighting of the reactive components shifts depending on the type of cable selected. This results in overshoot, resonance, damping and other phenomena.

This paper will primarily deal with block Co (the contact transition resistance) because it has always been neglected. It can be assumed that in industrial systems and test systems, the process energy source, the supply lines, and the measuring sensors are known, so the contact of the structure is known but can vary greatly depending on the individual and application.

Fig. 2 compares an optimal supply line of approx. 100 mΩ (dashed red) with different gap widths and electrolyte conductivities. A critical working condition arises from around 8 cm² of the work area because the resistances from the process, the supply line and, as can be seen later, also from the contacting are of the same magnitude. For smaller working surfaces, it is possible to balance is fact by electrolyte conductivity and working gap.

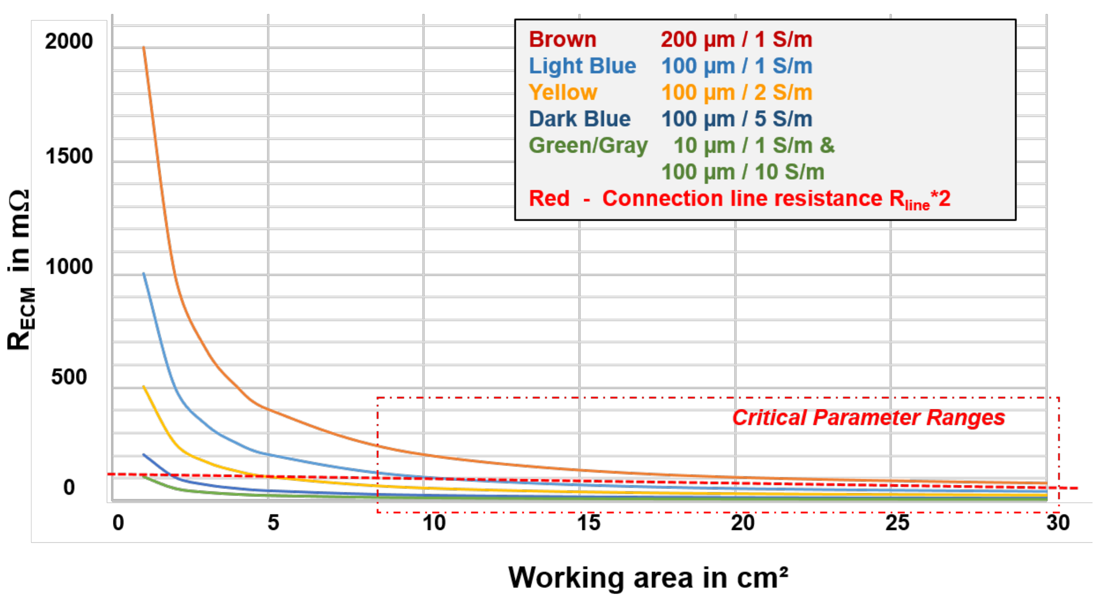

Fig. 2: Comparison of different working parameters with the optimal connecting lines – Legend are working gap / electrical conductivity. Legend ranking is identical with calculated curve ranking

More generally, the current density-potential curves of anodic metal dissolution describe the situation in Fig. 3. A change in the overall impedance causes a shift in the process potentials and/or the current density. The shifting of operating point is described in [1,2].

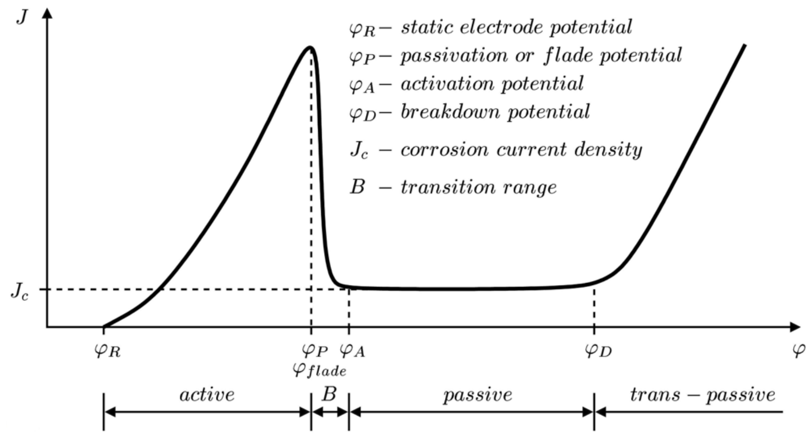

Fig.3: General current density-potential curve for passivating electrolyte as a criterion for a possible potential shift due to a change in contact resistance

Experimental Setup

The explanations and descriptions in [3,4] were the inspiration for the experimental setup. The aim of the experimental setup (Fig. 4) was a test section that was as reproducible as possible so that the different cable lugs made of different materials could be sufficiently comparable. Seven to nine measurements in chronological order and at least two series of measurements were evaluated.

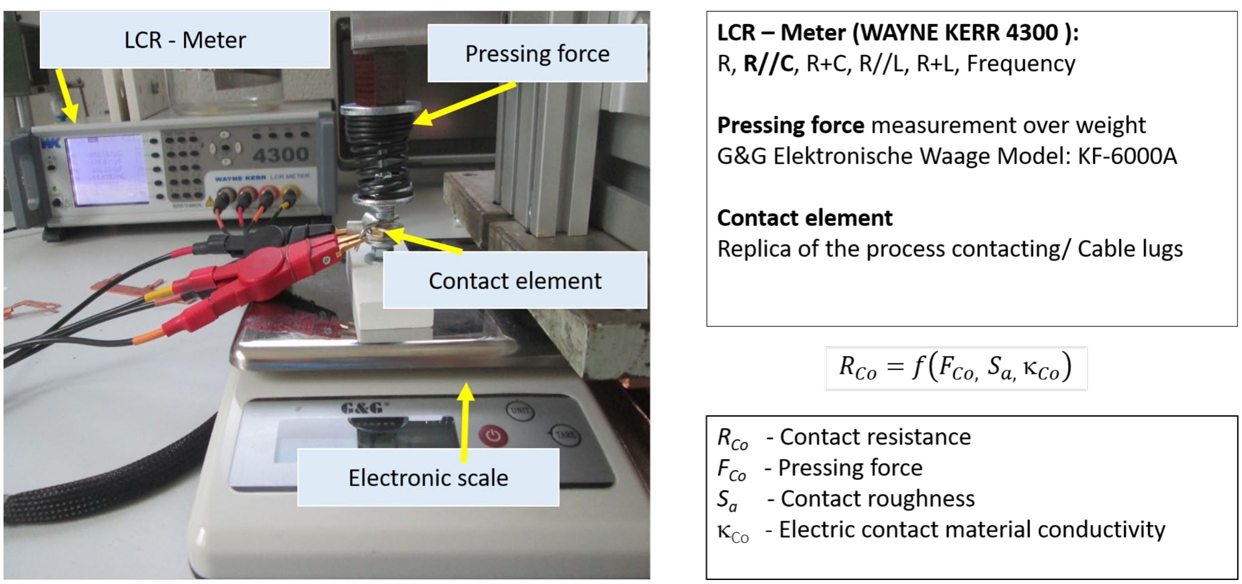

Fig. 2: Experimental setting for measurement of contact resistance

The cable lug is on a 10 mm diameter brass base positioned. A wire on 4 mm is pressed onto the cable lug from above. The deflection of a spring creates the force on the wire. A scale (Fig. 4) is used as a force sensor, and the displayed weight values are converted. For each set force, the resistance for the DC measurements was done using an mΩ-meter, the impedance amount $|Z_{Co}|$ was measured using an LCR-meter, and additional the phase angle for the AC arrangements was measured. For the correct contact impedance, the arrangement without a cable lug is determined and subtracted from the measured values. The arrangement without a cable lug is determined and subtracted from the measured values for the correct contact impedance. Open and short calibration will supported by a newer four-wired measuring device. However, it is also possible to determine the impedance of the measuring arrangement and then implement the compensation in post-processing.

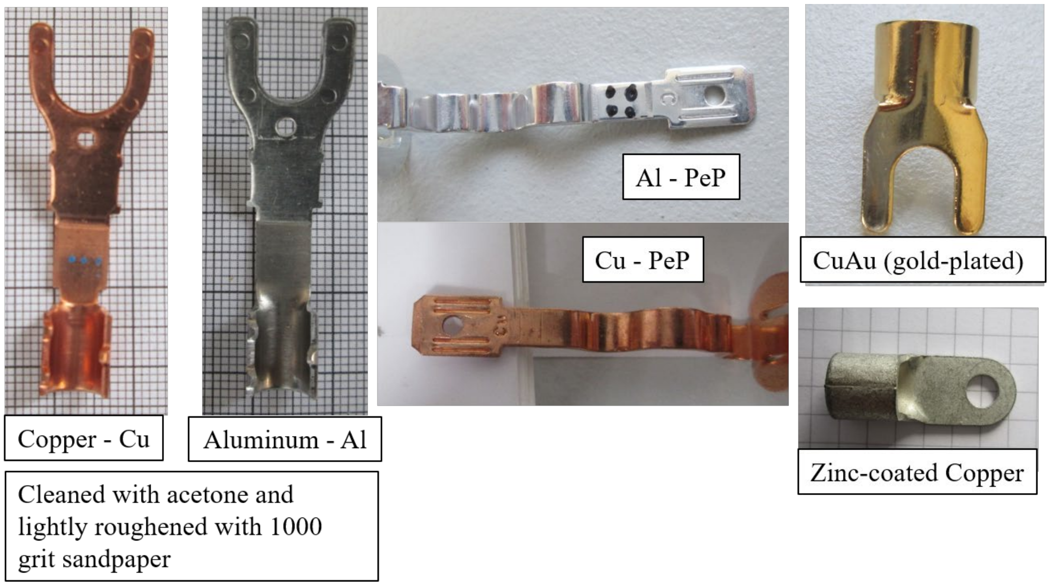

Fig. 3: Cable lugs for the investigation

The measuring range for the contact force was limited by the secure contact up to 80% of the scale load, corresponding to a contact force of 5 N to 45 N. Copper and aluminum were preferred as materials. Surfaces cleaned with acetone and roughened with 1000-grit sandpaper or plasma-electrolytic polished were tested. Attempts by increasing and decreasing contact force verify selected measurements. The different cable lugs for investigation are to be seen in Fig. 5.

The linear load in the test setup makes a comparison between different contact surfaces possible. However, it can be seen from Fig. 2 that for contact resistances less than 5 mΩ, the influence of the contact can be neglected. Influences up to 10 mΩ are very dependent on the gap width and electrolyte conductivity; up to a limit of 20 mΩ, the gap voltage has to be corrected. Beyond 20 mΩ, it is essential to determine the real gap voltage and the possibly changing working current so that the results remain comparable to other experiments. Under certain circumstances, the conditions can mean that the removal process (ECM or Electro-Discharge Chemical Machining (EDCM)) is no longer possible (Fig. 3).

Galvanized copper cable lugs and gold-plated cable lugs were examined as further comparison materials (Fig. 5). To preserve the coating, these parts were only cleaned with acetone.

Experiments with a direct voltage source (DC arrangement)

Processing with DC voltage is still important for the ECM. Therefore, cable lugs were measured in the DC arrangement. The DC arrangement shows three characteristic phases in the dependence of the contact resistance R_{Co} on the contact force F_{Co}.

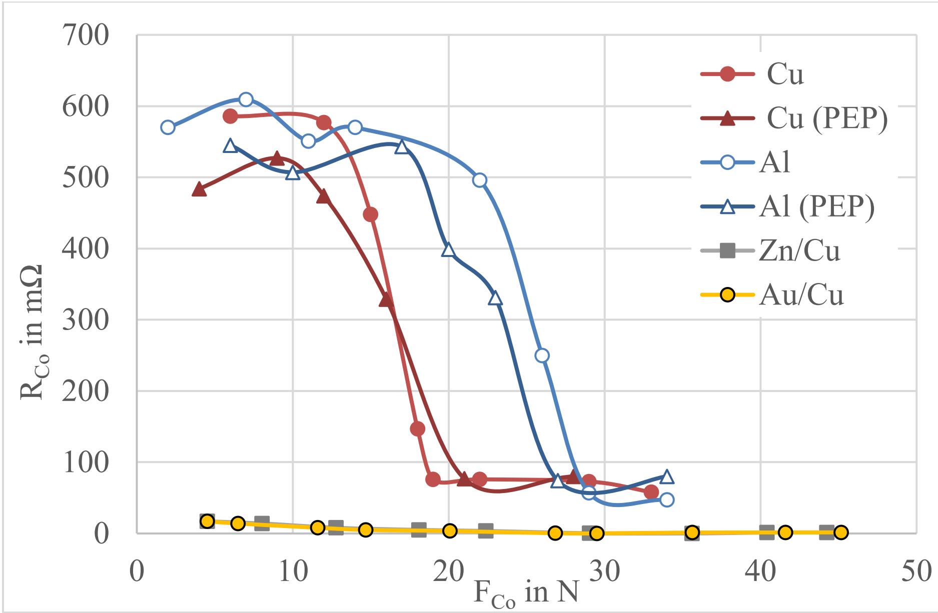

Fig. 4: Contact resistance for different Cable lug materials using the DC application

Samples without coating have a 500 mΩ to 600 mΩ contact resistance at low contact forces of less than 20 N. This is, therefore, significantly larger than the supply line resistances and the process state. In the second phase, there is a bend in the R_{Co} curve. The contact force is increased by 10 N, so the contact resistance is below 100 mΩ. The exceptions are the coated cable lugs; their transition to complete contact occurs below 10 N. What they have in common is the use of an intermediate medium that is ductile enough to adapt to the surface of the contact partner, even at low forces. The examples chosen here also deal with oxidation. With R_C values of 40 mΩ to 80 mΩ and the requirement that there are at least two contacts, significant corrections to the actual Process Energy Source (PES) voltage are necessary in order to achieve the desired gap voltages. The repetitions of the measurements with DC show qualitatively the same behavior and quantitatively larger deviations. Contact forces of greater than 25 N are necessary to achieve contact resistances of less than 80 mΩ for pure materials.

Experiments with AC applications at different frequencies

In the case of AC applications, the magnitude and the phase angle Φ of the impedance was $|Z_{Co}|$, was measured.By this, it can be determined how large the resistance component and the capacitive component are.

Contact impedances of 20 mΩ to less than 1 mΩ were determined for the coated cable lugs. Since the phase angle was consistently close to 0° (100 Hz), this corresponds to a purely ohmic contact resistance in this range. From 15 N upwards, the contact resistance values are below 5 mΩ, and the ohmic component can therefore be neglected. Since the pulse durations of 10 ms correspond to this frequency, there are no corrections for the gap voltage for the ECM.

For the 100 kHz test frequency, the result is a very low-value level of less than 15 mΩ, as shown in Fig. 7. This frequency corresponds to a pulsation of 10 µs, which is below the pulse durations primarily used today. The two materials show very different behavior. The galvanized cable lug

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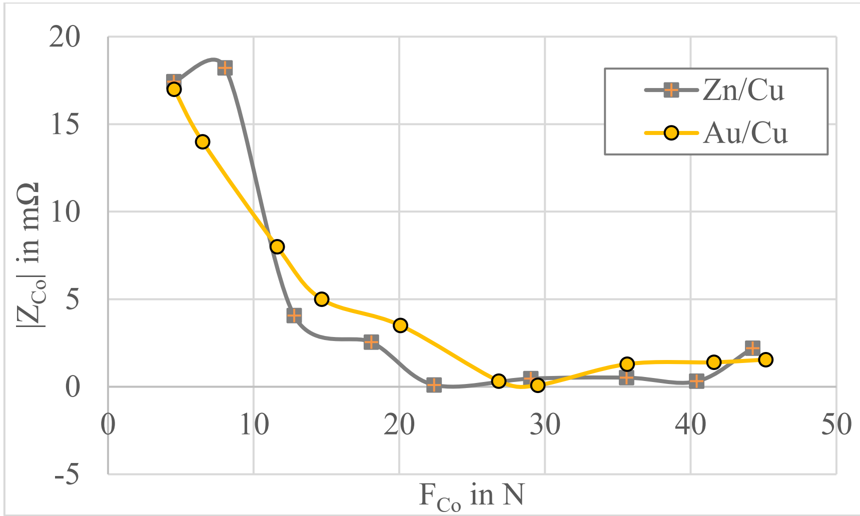

Fig. 5: Magnitude of impedance for the coated cable lugs at 100 Hz

shows an almost constant contact impedance of 7 mΩ, while the phase angle increases from 70° to 87°. This means that the ohmic component at 10 N is approximately 2.40 mΩ, while at 35 N it drops to 0.37 mΩ. The contacting has a primarily capacitive effect for all contact forces. For the gold-plated cable lug, there is a slightly increased R_{Co} value of 15 mΩ for 3 N, while it then drops almost to 3 mΩ to 1 mΩ. In the case of the phase angle, there is a sharp increase from 5° at 8 N to 87° at 37 N. Therefore, there is a change from the purely ohmic component (14.8 mΩ) to an almost purely capacitive behavior with an ohmic component of 0.06 mΩ . For an R_{Co} value of 1.7 m, there will be an average contact force of 20 N.

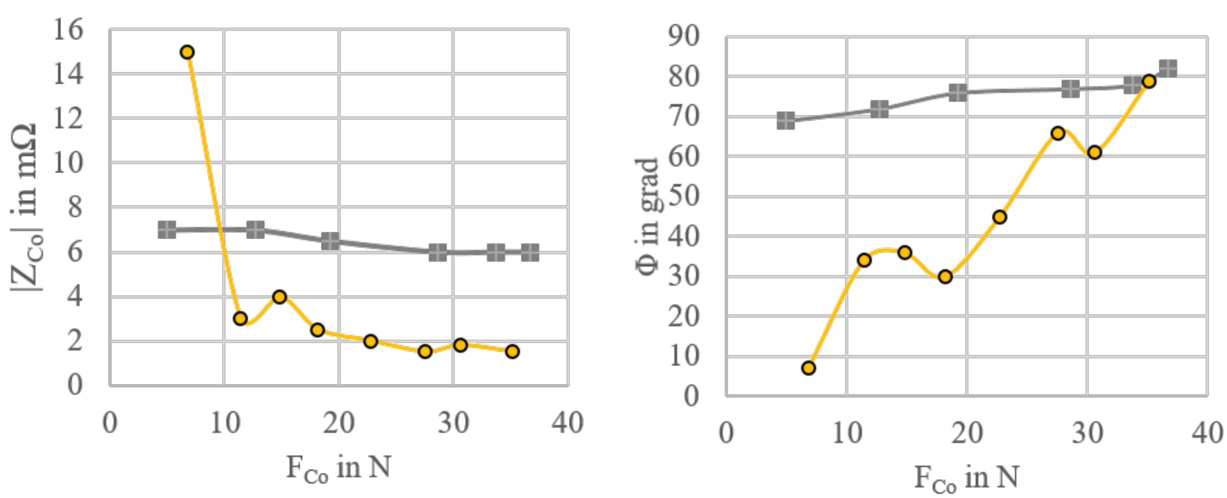

Fig. 6: Magnitude and phase of contact impedance at 100 kHz – Square is Zn/Cu and circle is Au/Cu

AC application by different surface characters for Al

Using aluminum as an example, we want to show the influence of surface formation on contact resistance. Three different surface conditions were examined. Firstly, with acetone cleaned, Al. Secondly, it was roughened with 1000 grit sandpaper and thirdly, the contact surfaces were plasma electrolytic polished.

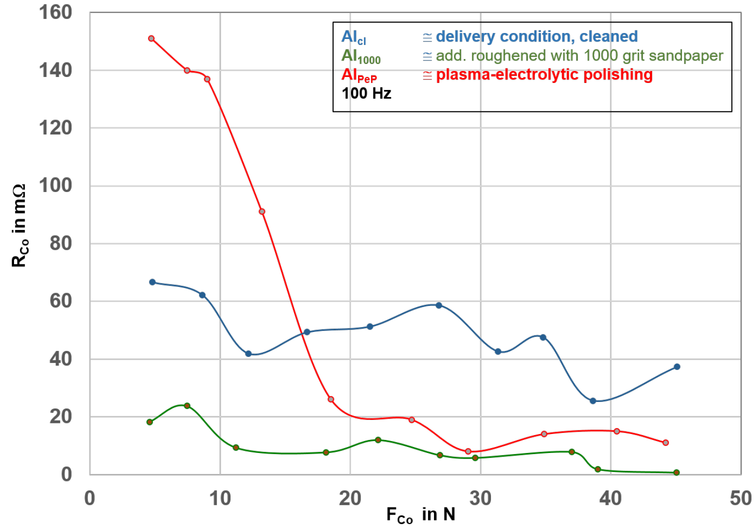

Fig. 7: Comparison of different contact surface modifications for Al by 100 Hz

The 100 Hz investigations show an almost purely ohmic load, because the phase shift is close to zero. Then, in Fig. 9, the impedance can also be replaced by the value of R_{Co}. The simply cleaned cable lug (circle) shows increased contact resistances between 70 mΩ and 25 mΩ, which does not correspond to the ideal contact resistance requirements. This may be because the aluminum surface oxidizes easily in the air, resulting in an increase in R_{Co}. The cleaned and corrosion-resistant surface created by PeP treatment (triangle) still has contact resistances of 150 mΩ to 60 mΩ at small contact forces of less than 15 N. Above, it falls below 20 mΩ and can, therefore, be neglected. The most favorable behavior is the roughened cable lugs, which are 20 mΩ and smaller in the tested contact force range. From 25 N, the contact resistance drops to less than 10 mΩ. Phase response and impedances have to be considered separately for a frequency of 100 kHz. For the cleaned Al, the absolute impedance at 10 N is approx. 45 mΩ and the phase angle is 20° so the contact resistance is 42.3 mΩ. Already from 20 N, the absolute impedance is only 12 mΩ and the phase angle is 40°, which results in a contact resistance of 9.2 mΩ. The worst is the roughened cable lug surface, which almost always fluctuates between 40 mΩ and 60 mΩ for the absolute impedance and whose phase angle is between 35° and 20°. The amount of contact resistance, therefore, reaches values of 32.8 mΩ to 56.4 mΩ. These values are far from the optimally required ones. The behavior of the PeP-processed cable lugs is qualitatively interesting. Above 10 N, complete contact has been formed, and the phase behaves constantly.

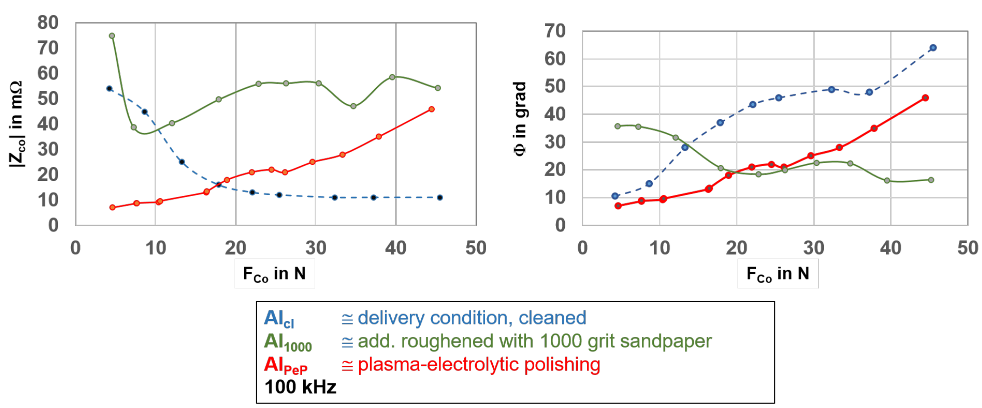

Fig. 8: Comparison of different contact surface modifications for Al by 100 kHz.

AC application by different surface characters for Cu

For the material Cu, only two surface modifications have been investigated: the slightly roughened surface with 1000-grid sandpaper and the PeP-processed contact surface. The oxidation here has a different effect on the contact resistance. For the 100 Hz tests, the phase angle is again 0°, and therefore, the measured impedance is equal to the ohmic component. Similar to Al_{PeP}, the contact resistances of Cu_{PeP} show constant behavior in the range from 5 N to 45 N. The roughened Cu_{1000} shows contact resistances of 100 mΩ to 60 mΩ at small contact forces (< 10 N), which do not meet the requirements of neglect. From 20 N, the contact resistance drops to 20 mΩ to 30 mΩ and only after 35 N falls below to 10 mΩ. The waviness in the curve can result from the ductile behavior of the copper under higher forces. This means that the optimal area of application is very limited to the high contact forces.

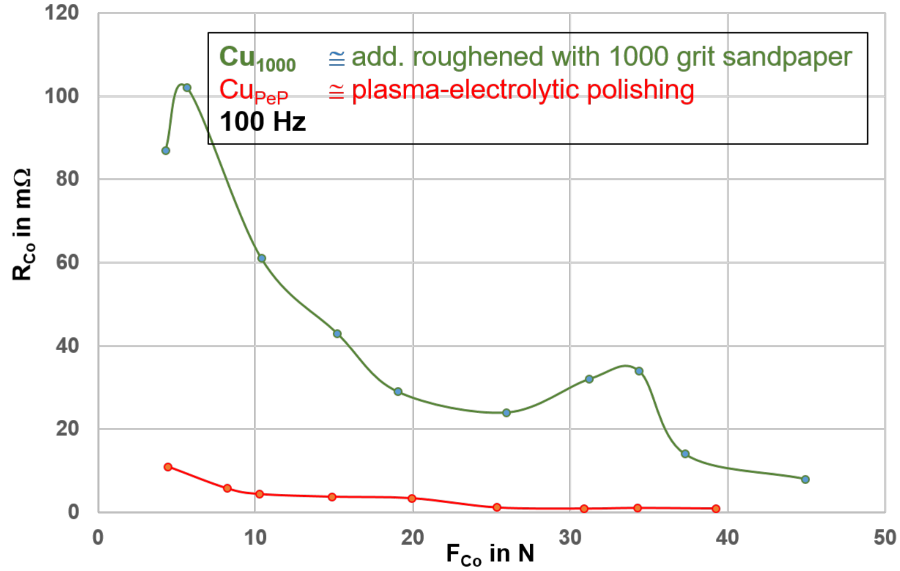

Fig. 9: Comparison of different contact surface modifications for Cu by 100 Hz.

In the case of the 100 kHz study, the contact resistance drops significantly, and the phase angle influences the contact resistance. The impedance amounts are between 27 mΩ and 3 mΩ and the phase angles are in a range of 20°. The PeP-processed cable lug already has an impedance of less than 10 mΩ and improves the phase angle to 8.5 mΩ. Simply roughening the surface results in small, better ohmic contact resistances of 4.7 mΩ to 4.2 mΩ.

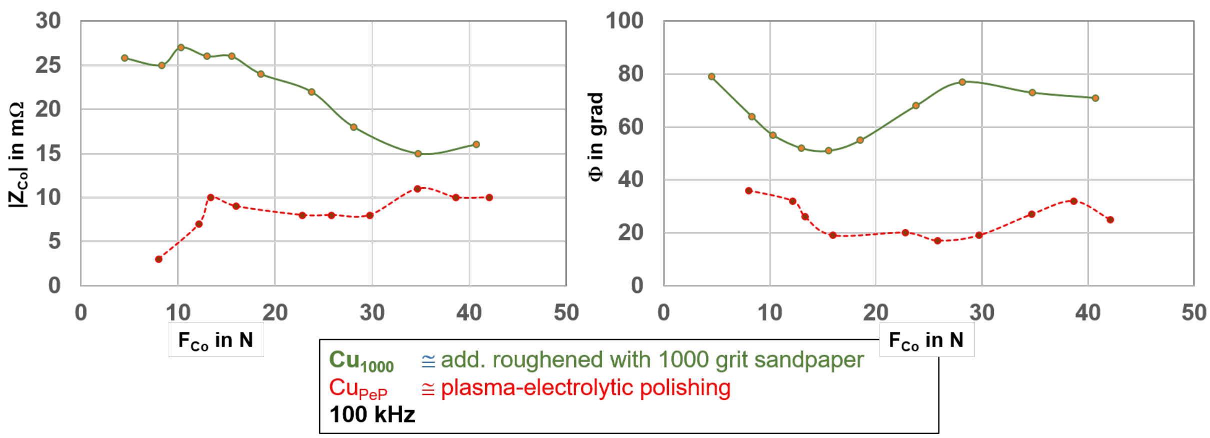

Fig. 10: Comparison of different contact surface modifications for Cu by 100 kHz.

Conclusion

The relationship between contact force and contact impedance is discussed in relation to workpiece clamping in ECM. The situation is problematic, when the contact resistance is in the same order of magnitude as the gap impedance of the ECM. In this case, the resulting current limitation limits machining productivity. A distinction must be made between the influence on DC processing and AC/pulse processing. As described in [3,4], there is a point at which the apparent and actual contact surfaces correspond to each other. For our DC studies, this range shows three above a contact force between 20 N and 30 N.

For AC or pulsed applications, in addition to the contact resistance, the influence of impurity or oxide layers must also be taken into account. These form an additional parallel capacitance to the ohmic contact resistance. Test specimens with different surface modifications are compared in order to work out this influence. Tin-plated and gold-plated cable lugs show the advantages of appropriately chosen coatings. If they are ductile enough and control the oxidation behavior for the environment.

Cu and Al samples show the influence of oxide layers on the impedance. For Al samples, the ohmic component of the contact resistance collapses when the contact force is sufficient. However, the parallel capacitance increases according to the contact force. The Cu oxide layer is more ductile than the Al oxide layer. The increase in pressure at Al shows a reduction in distance. For Cu, the reduction in distance and the increase in contact area work against each other.

Own investigations on plasma-polished surfaces show a reduction in these influences. Levelling the surface reduces oxide formation and foreign layer adhesion. However, the improvement in the ohmic component also depends on the roughness of the contact partner.

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