Maximisation of the achievable bond width in capacitor-discharge welding of annular axial seams on gear components

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Introduction

- Welding tasks in gear manufacturing include diameters up to 250 mm and cross sections up to 1500 mm².
- Capacitor-discharge-welding is a highly dynamic process in which the entire weld seam cross section is produced simultaneously in less than 40 ms by a high-current pulse of several hundred kiloamperes.
- Annular seams can be produced by at least one of the joining partners having an annular projection contour for the current density concentration needed.
- The simultaneously welding of the cross section and short welding times favor a low thermal distortion.
- The fast welding process runs event-driven, an intervention is not possible. This means that the welding result is already determined by the predefined input parametersat the start of the process.

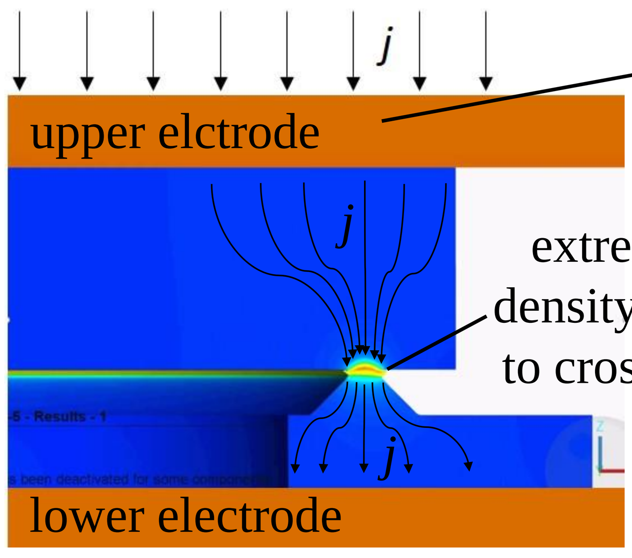
Basics of Capacitor-Discharge-Welding (CD-welding)

- Resistance pressure welding process, Joule resistance heating of the joint.
- Main field of application is projection welding.
- Energy supply through a capacitor-discharge.
- High pulsed welding currents up to 1000 kA.
- Extremely short welding times (~1 – 40 ms)

Joule heating:

$$\dot{q} = \frac{\dot{Q}}{A_L} = j^2 \cdot R$$

$\dot{q}$... heat flux density
j... current density
R... ohmic resistance
$\dot{Q}$... heat flux
A_L... conductive cross section

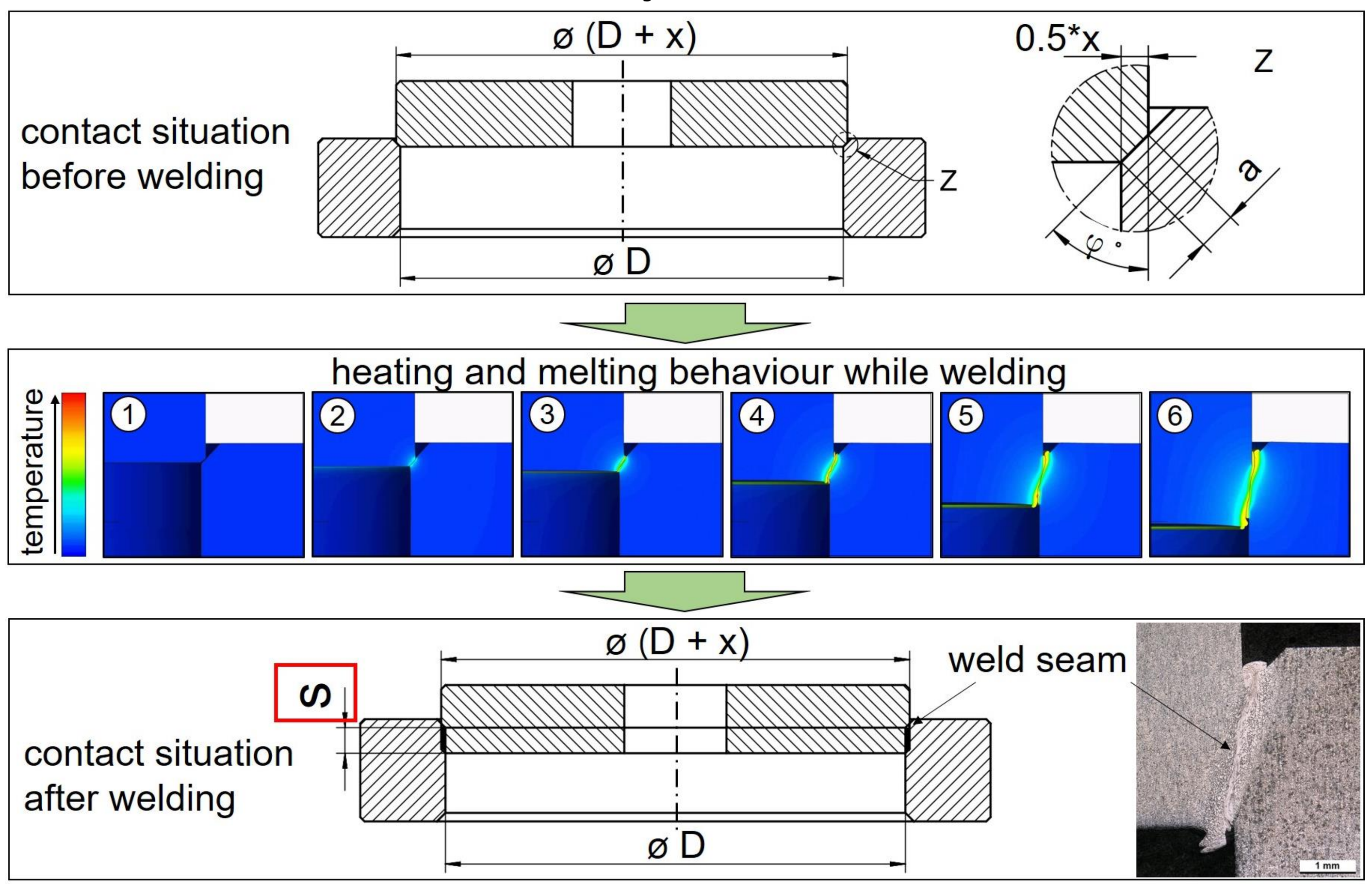


homogeneous current density j distribution

extremely increased current density j and resistance R due to cross-section A_L reduction.

CD-welding of annular axial seams

- An oversize $\boldsymbol{x}$ on at least one part is used as projection geometry.
- The contact geometry before welding can be described with the oversize $\boldsymbol{x}$, the contact angle $\boldsymbol{\varphi}$ and the resulting contact width $\boldsymbol{a}$.
- Under pressure and heating, the parts sink into each other by the melt distance $\boldsymbol{s}$, that is directly related to the achieved bond width.



Arrangement of the joining partners for CD-welding of annular axial seams.

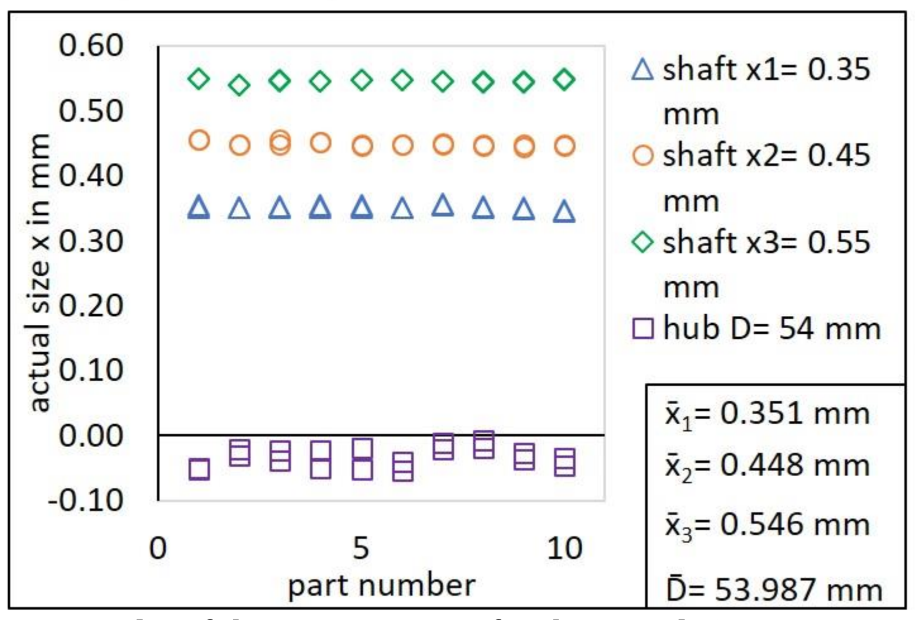
Problem statement und objective of the investigation

Data points filling: ◇ no spattering ◆ slight spattering ◆ strong spattering

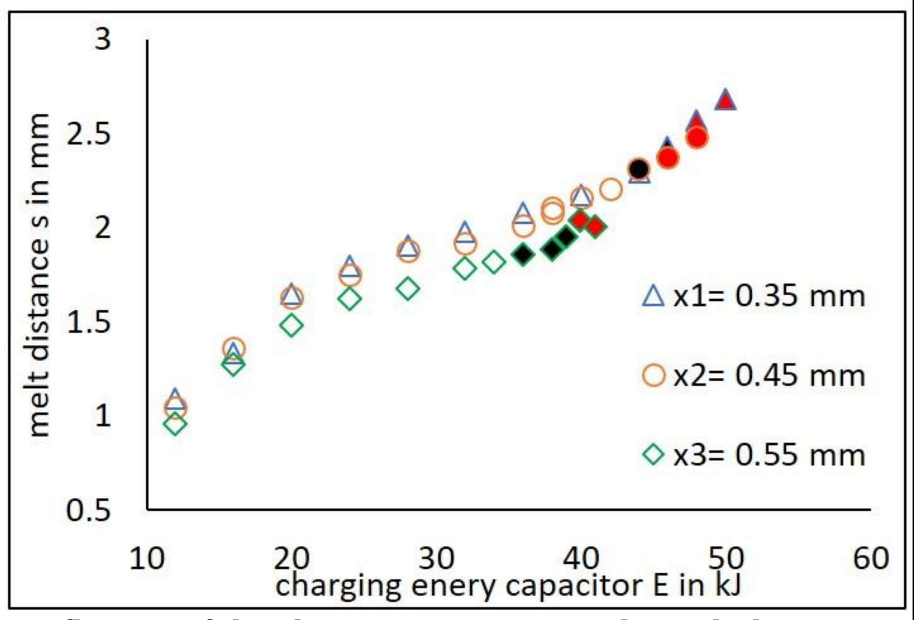
- For a high possible load-bearing capacity, large bond widths are required between the joining partners in car transmission constructions.
- In CD-welding, only a certain amount of energy can be supplied into the process and a certain bond width can be achieved before weld spatters occur, which is not permissible.
- **The aim of the study is therefore to investigate the influence of various input parameters on the achievable bond width before macroscopic weld spatters occur**.

Influence of the oversize x

- Achievable bond width for different oversizes $\boldsymbol{x}$ is studied.
- First, the actual average size of each oversize $\boldsymbol{x_1}$ - $\boldsymbol{x_3}$ (shaft) and the actual diameter of the hub $\boldsymbol{D_{hub}}$ (10 samples from each geometry) was measured: $\boldsymbol{x_1}$= 0.351 mm, $\boldsymbol{x_2}$= 0.448 mm, $\boldsymbol{x_3}$= 0.546 mm, $\boldsymbol{D_{hub}}$= 53.987 mm.
- Welding conditions: electrode force F= 60 kN, current rise time t_p= 11.3 ms, repositioning stiffness k= 8.5 kN/ mm.



Results of the measurement for the actual size $x_1 – x_3$.

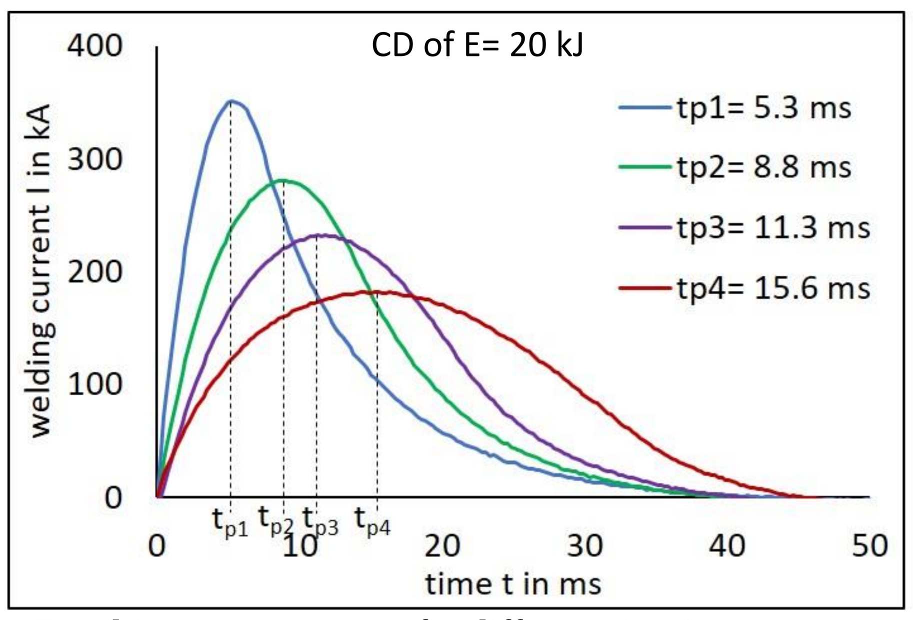


Influence of the charging energy E on the melt distance s.

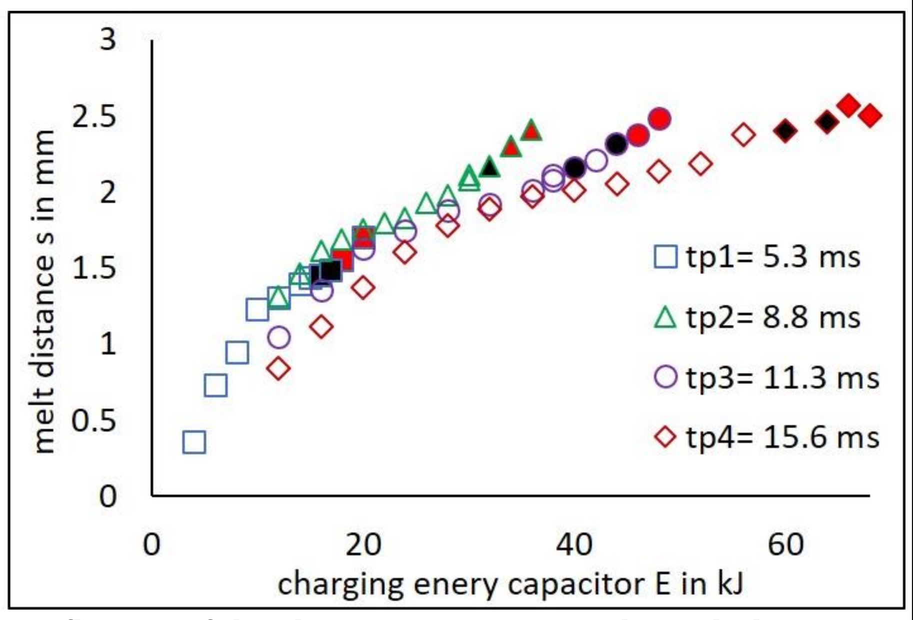
⇨ **Too large oversizes x lower the achievable bond width!**

Influence of the current rise time t_p

- For higher charging energys E the peak current I_p rises, but weld times stay constant.
- Achievable bond width for four different current rise times $\boldsymbol{t_p}$ is studied.
- Configurations: $\boldsymbol{t_{p1}}$= 5.3 ms (C= 8 mF, $ü$= 1:120), $\boldsymbol{t_{p2}}$= 8.8 ms (C= 24 mF, $ü$= 1:120), $\boldsymbol{t_{p3}}$= 11.3 ms (C= 24 mF, $ü$= 1:160), $\boldsymbol{t_{p4}}$= 15.6 ms (C= 24 mF, $ü$= 1:240).
- Welding conditions: electrode force F= 60 kN, oversize x= 0.45 mm, repositioning stiffness k= 8.5 kN/ mm.



Resulting current curves for different rise times $t_{p1} – t_{p4}$.

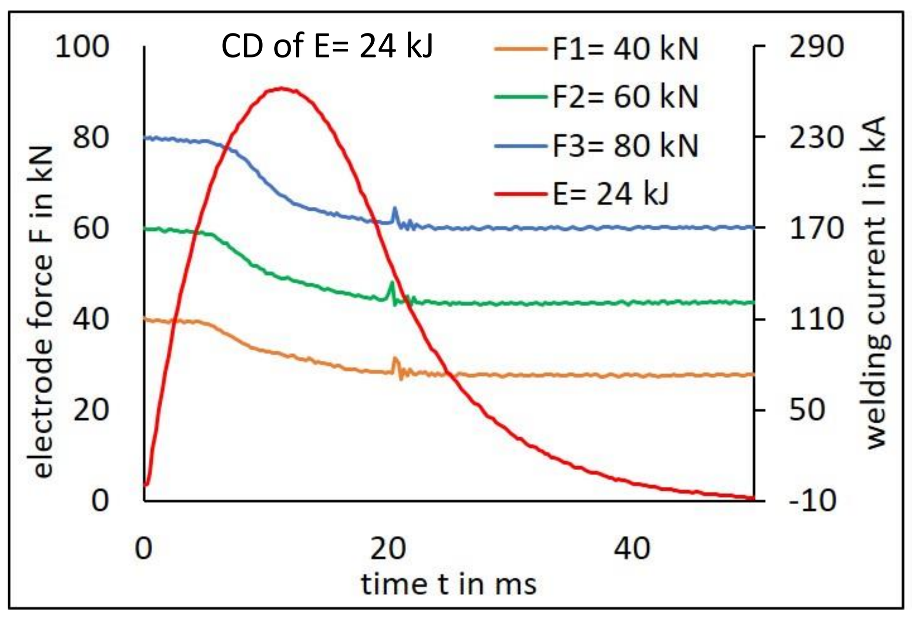


Influence of the charging energy E on the melt distance s.

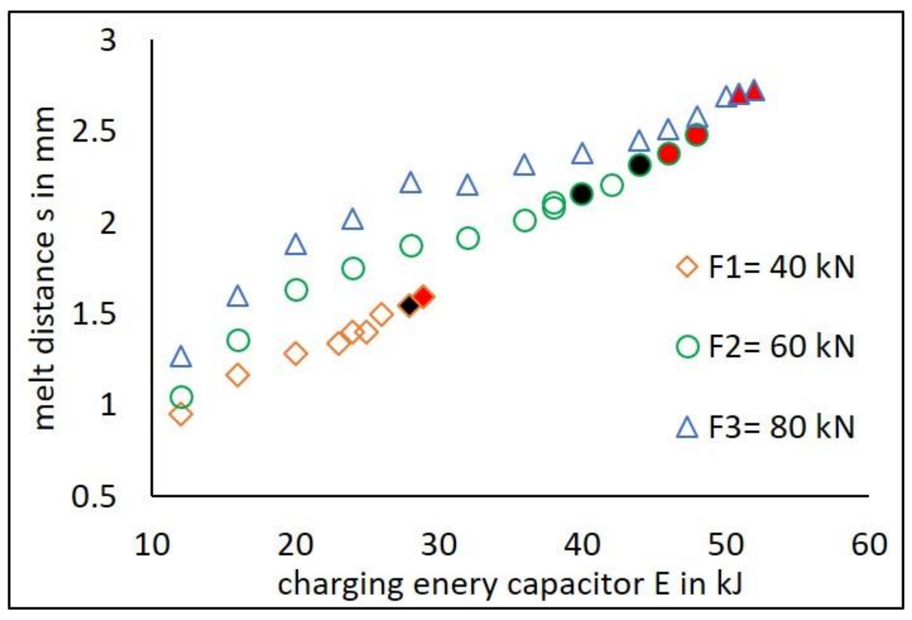
⇨ **Too short current rise times t_p severely restrict the achievable bond width!**

Influence of the electrode force F

- Achievable bond width for three different electrode forces $\boldsymbol{F}$ is studied.
- First, the resulting contact situation (width a and pressure p) before welding was measured for the different forces $\boldsymbol{F_1 – F_3}$: $\boldsymbol{F_1}$= 40 kN → a_1= 0.33 mm, p_1≈ 708 MPa, $\boldsymbol{F_2}$= 60 kN → a_2= 0.44 mm, p_2≈ 753 MPa, $\boldsymbol{F_3}$= 80 kN → a_3= 0.51 mm, p_3≈ 758 MPa.
- Welding conditions: current rise time t_p= 11.3 ms, oversize x= 0.45 mm, repositioning stiffness k= 8.5 kN/ mm.



Resulting Electrode forces $F_1 – F_3$ over the welding time.

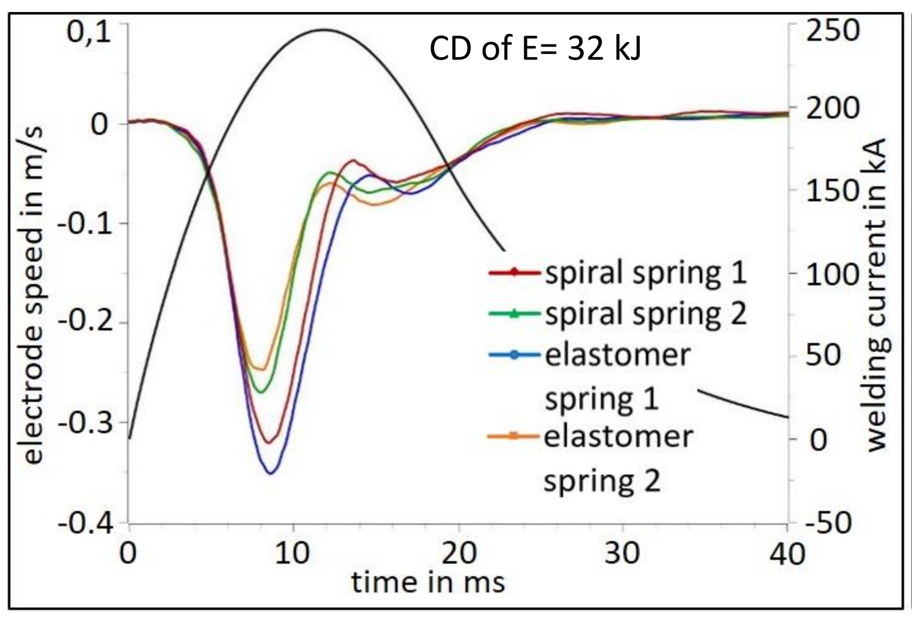


Influence of the charging energy E on the melt distance s.

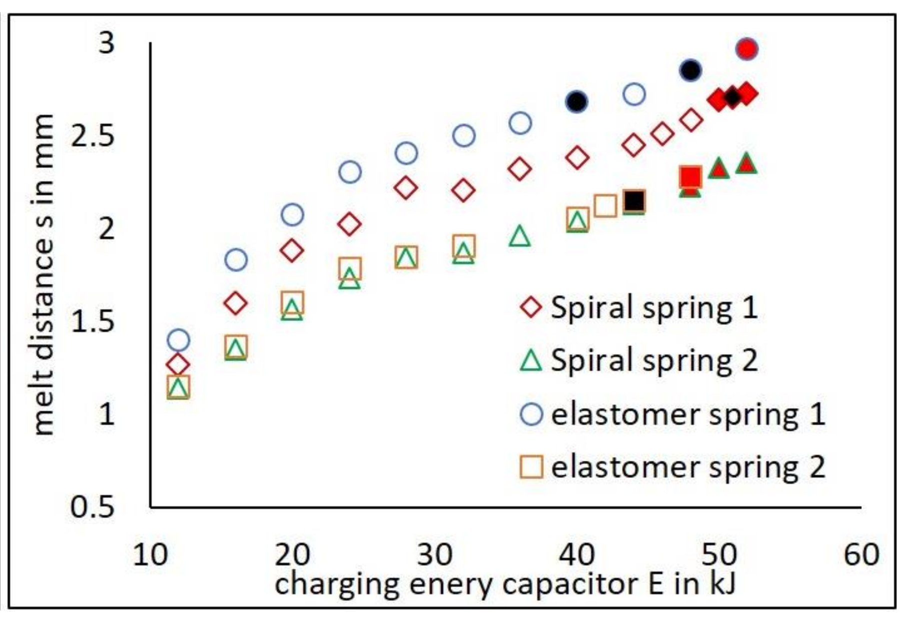
⇨ **Too low electrode forces F severely restrict the achievable bond width!**

Influence of the spring stiffness k (repositioning unit)

- Achievable bond width for four different spring stiffnesses $\boldsymbol{k}$ is studied.
- Two spiral spring packages (linear) and two elastomer spring packages (progressive).
- Spiral spring package 1: $\boldsymbol{k}$= 8.5 kN/ mm, Spiral spring package 2: $\boldsymbol{k}$= 18.7 kN/ mm.
- elastomer spring package 1: $\boldsymbol{k}$≈ 3 kN/mm, elastomer spring package 2: $\boldsymbol{k}$ ≈ 10 kN/mm
- Welding conditions: current rise time t_p= 11.3 ms, oversize x= 0.45 mm, electrode force F= 60 kN.



Resulting electrode speed v for different springs over time.



Influence of the charging energy E on the melt distance s.

⇨ **Too high spring stiffnesses k (+ slow $v_{electrode}$) lower the achievable bond width!**

Summary

- All four investigated parameters (oversize $\boldsymbol{x}$, current rise time $\boldsymbol{t_p}$, electrode force $\boldsymbol{F}$ and spring stiffness $\boldsymbol{k}$) have a decisive influence on the achievable bond width.
- In particular, short current rise times $\boldsymbol{t_p}$ and low electrode forces $\boldsymbol{F}$ lead to a premature weld splatter formation and therefore severly restrict the archievable bond width!
- For the studied diameter of 54 mm to be welded, melt distances $\boldsymbol{s}$ (and therefore bond widths) of up to 3 mm could be achieved without weld spatter formation occuring.

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