TECH

Technical backgrounder from EFD Induction

Consistent quality in high-frequency tube and pipe welding

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Abstract
The authors evaluate the parameters influencing weld quality and scrap production in high-frequency tube and pipe welding. The paper focuses on the welder. Two stages of the production process – steady state operation and non-ideal conditions – are investigated. The parameters involved are ripple in output power and short circuits in the load.

Maximum throughput in a high-frequency tube and pipe mill is achieved by a welder that offers high uptime, consistent high-weld quality, flexibility and high total electrical efficiency. High uptime is a prerequisite for high throughput and was addressed in the paper "Maximising uptime in high-frequency tube and pipe welding"1. This paper focuses on how to achieve consistent high weld quality.

Consistent quality minimises scrap
Ripple in the output power is a well-known challenge when trying to obtain consistent welding temperatures. The welder power supply's rectifier converts the AC mains supply voltage and current to DC voltage and current. This is then fed to the inverter, creating the power supply's high frequency alternating output voltage and current.

The most widely used rectifier types are the diode rectifier and the thyristor controlled rectifier (SCR). Both of these are of the line-commutating type and will, therefore, be the origin of the ripple on the DC voltage and current.

Should no action be taken to avoid ripple in the output power, the weld temperature will vary with a stable ripple frequency dictated by the mains frequency. 50 and 60Hz mains supply results in 300 and 360Hz ripple frequency, respectively. The consequences of such a ripple depend heavily on the magnitude of the ripple. There are two situations in which the ripple can negatively impact weld quality. The first is at a high weld speed on small tubes. For weld speeds in the 150-200m/min (~500-650ft/min) range and tube outside diameter in the 12.7-15.9 (1/2"-5/8") range, and with a distance of around 32mm (1.25") from induction coil to weld point, the heating time of the strip edges will be 9-13ms. This corresponds to 3-4.5 times the cycle time for 300-360Hz ripple. To further describe the situation, we look at two 'infinitely' small volumes of material in the strip edges on their way towards the weld point, as shown in Figure 1.

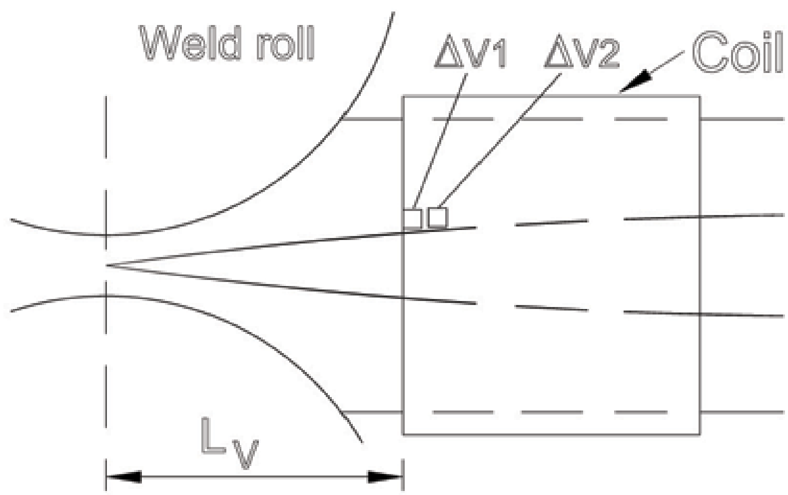

Figure 1: Heating length Lv of volumes

The volume ΔV1 enters the weld zone first and the heating time is given by the length Lv and the weld speed. Volume ΔV1 experiences a power that is related to the DC voltage indicated in Figure 2, which shows the non-smoothed DC voltage when using a passive diode or thyristor-controlled rectifier (at full power). Volume ΔV2 enters the weld zone just after volume ΔV1 and will be heated during an equally long heating time as ΔV1, in this example 4.25 times the cycle time of the ripple. But ΔV2 will face a different power input, indicated by the corresponding DC voltage in Figure 3. Due to the ripple and the different starting point with respect to time, the average voltage (and power), indicated by the shaded areas, will be different, since A11/4 is less than A21/4. At a lower weld speed the heating time is longer. Using 8.25 times the cycle time of the ripple as an example, the difference in total area, due to the difference in A11/4 and A21/4, will be almost half the value at the high speed. This shows that the ripple has a larger impact on weld power stability at high speeds than at low speeds.

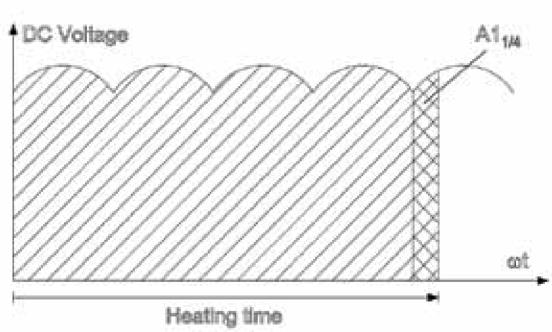

Figure 2: DC voltage during power input to volume ΔV1

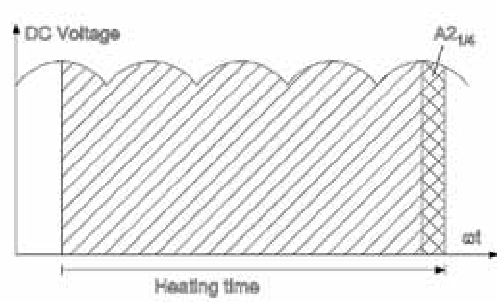

Figure 3: DC voltage during power input to volume ΔV2

The second situation where the amount of ripple often plays an important part is high-frequency welding of stainless steel tubes. These steel types contain a substantial quantity of chromium that oxidises during welding. The chromium oxide, together with other oxides, forms a hard refractory material with a higher melting point than the base steel. Unless the weld temperature is increased to get molten material across the whole faying surfaces, these solid particles are trapped inside the weld due to poor squeeze out. Conversely, if too much material is melted, the weld vee may become unstable, with possible weld defects as a result. The temperature window when welding stainless steel is, therefore, narrower than for low carbon steel, and a ripple in output power will have a larger effect on weld quality and scrap production.

There are three ways to handle the unwanted ripple: install smoothing circuitry (DC capacitor, DC choke or both), regulate power after rectification of the AC mains, or a combination of these two alternatives. The first option is the only one for vacuum tube and solid state welders with a controlled rectifier (SCR). These welders rely solely on installed smoothing and filtering circuitry, which tends to be rather heavy and bulky equipment. Some welder manufacturers have minimised smoothing circuitry, and instead added extra filters in units for stainless steel welding.

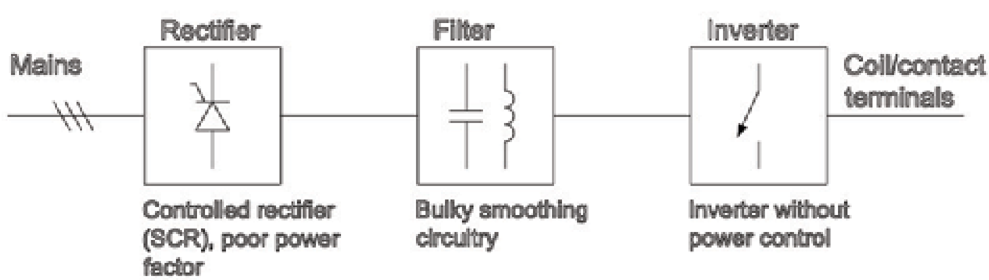

Figure 4: Converter structure, power control in the SCR

Maladjustments or control electronics timing problems of the SCR can create non-symmetric stress and reduced service intervals or lifetime of a mains transformer in the factory's power supply grid. Misfiring of the rectifier's switches can also lead to a higher ripple at an even lower ripple frequency, thereby increasing the risk of weld quality problems, even at lower weld speeds. It is then a question whether the DC smoothing circuitry is sufficiently dimensioned to cope with such non-ideal **ope**ration. It is not possible to remove this problem by power regulation at a later stage in the converter.

The second option – to handle the unwanted ripple with regulation only, without any filtering components – is rarely employed. Some energy storage devices to secure energy for regulation are necessary. The smoothing circuitry also has a positive effect on the mains power supply's power factor2.

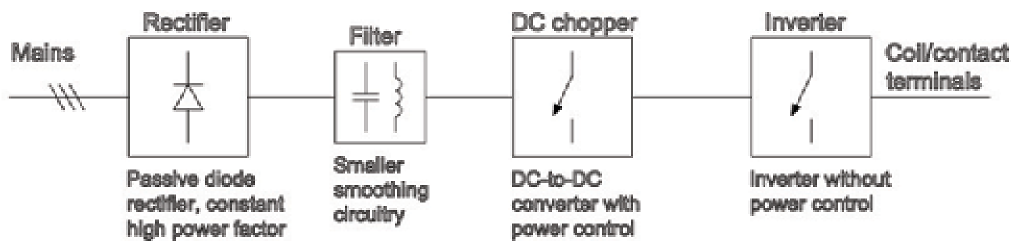

Figure 5: Converter structure, power control by a DC chopper

The third alternative with power regulation after the rectifier, together with some smoothing circuitry, is possible in welders where a DC chopper or the inverter takes care of the power control. In this case the rectifier can be of the passive diode rectifier type. The switching frequency of the DC chopper is many times higher than the mains supply frequency, making the chopper response time fast enough for proper regulation. Power control in the inverter, as in the Weldac from EFD Induction, operates directly on the weldfrequency level and is the market's fastest power regulation, reducing ripple to a minimum.

Some claim it is best to have a passive smoothing circuit, and not depend on electronics for smoothing the ripple. However, this approach requires attention to the overall use of regulation circuitry. Solid state welders with controlled rectifier require control electronics for the rectifier and the inverter. Welders with diode rectifier and DC chopper require electronics for controlling the DC chopper and the inverter. Welders with diode rectifier and power control in the inverter require control electronics for the inverter only. The ripple reduction circuitry is an inherent part of the power control for the two latter types of welders.

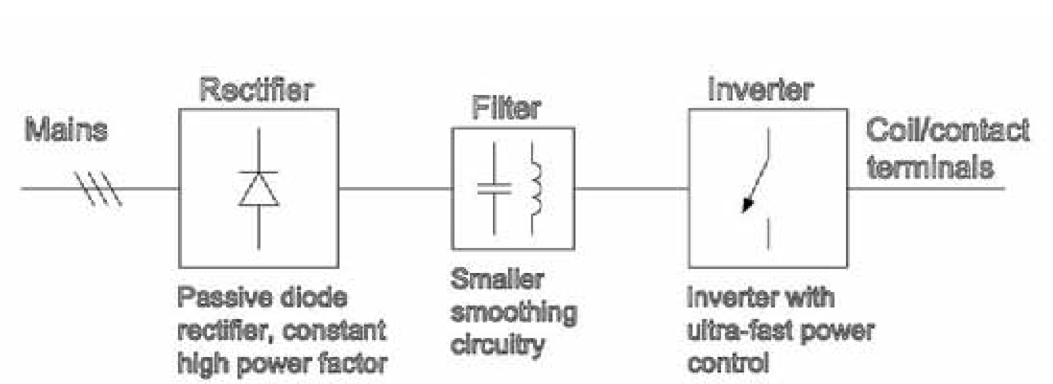

Figure 6: Converter structure, power control in the inverter

A welder with diode rectifier, some smoothing circuitry and ultra-fast regulation in the inverter, as close to the load as possible, is the best overall solution. The converter topology is shown in Figure 6. As a standard feature, the EFD Induction Weldac guarantees output power ripple to be less than 1 per cent, even with distorted mains supply in the factory. This makes it well suited for high-speed lines and stainless steel welding without the installation of extra smoothing circuitry. Minimising ripple in output power is important for achieving good weld quality during steady-state operation. The loss of a welder's steady-state operating condition is usually caused by a short circuit in the load. In case of severe arcing, the impedance change of the load can move the welder's operating point out of the full power matching range. It is essential for reduced scrap production that the welder re-establishes steady-state operation when the short circuit burns off. Fast frequency and output current and power regulation are obvious benefits in this respect.

The EFD Induction Weldac has electronic automatic matching and a broad matching range. It rapidly alternates between the different load impedances and quickly reverts to the steady-state point. The output power and current regulation is implemented in the inverter, enabling the market's fastest regulation and minimising 'non-welded' segments (pin holes, etc.) in the final product. Arcing is always a consequence of mechanical irregularities in the strip edges caused by poor slitting and forming, or a too narrow vee angle. In case of severe arcing, actions regarding mill set-up must be taken.

Conclusions

An evaluation of the parameters influencing quality and scrap production concludes:

- Stable weld temperature requires a weld output power without ripple. A welder with a passive diode rectifier, some smoothing circuitry and rapid power regulation in the inverter is the best overall solution. Particularly in order to meet the strict requirements of high speed mills and mills producing stainless steel.
- Recovery after short circuits in the load is optimised by welders with ultra-fast power regulation in the inverter.

References

1 "Maximising uptime in high-frequency tube & pipe welding"; B Grande, JK Langelid, O Waerstad, Tube & Pipe Technology, March 2011

2 N Mohan, WP Robbins, TM Undeland, (1989) Power Electronics: Converters, Applications and Design, John Wiley.

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