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Efficient welding processes and automation in modern production

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Summary:

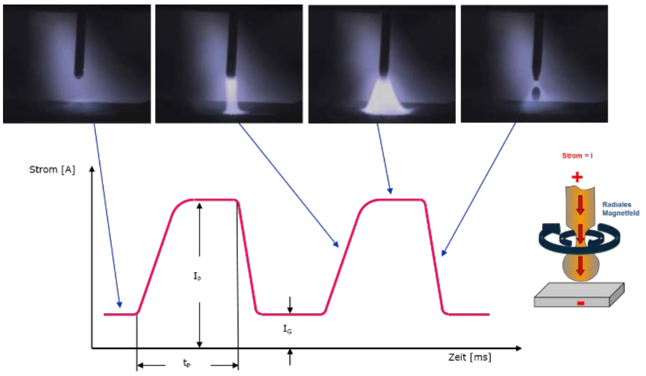
The metal machining industry and the trade belong to the most important producing economic sector in Germany. Because of its high degree of international networking, the German economy is more and more dependent on the world economy and is constantly in comparison with other economic nations. As a result, industry contractors must always keep in mind the efficiency of their production and track research and development trends in production engineering, automation and digitisation. Welding technology plays a significant role for the metal machining industry. So companies from this sector are often leaders in the development and use of new manufacturing and joining processes in production. While MMA welding is used on sites still quite often, companies with an own production implement more and more automated production systems. Here new and modern welding processes are used in addition to the conventional gas-shielded arc welding (MIG/MAG). With this report we want to list the most important new welding processes and present them with regard to their efficiency. On the conventional basis, different variants of MIG/MAG single wire processes, the MIG/MAG Tandem welding with two welding electrodes and welding with different lasers belong to them. The metal machining industry offers major areas of use and development potential in the automation field, too. Robot applications in combination with sensor technology are becoming increasingly common in this industry, often characterised by single and series production. In this article, we hope to provide a quick overview of the use of current welding processes and examples of the use of automated production systems in different applications.

1. Introduction:

For a foreign trade-focused country such as Germany, a powerful, internationally competitive, metal machining industry is of immense significance to the overall economy. The term "Made in Germany" is still today a quality brand for goods produced in Germany and puts the producing industry on an internationally well accepted pedestal. It is therefore necessary to maintain and to increase the sector's efficiency and productivity at a high level over the long term, in order to keep pace, in particular with global competitors. At the same time, the efficiency in production must not suffer from the enormous pressure so that in future goods with the "Made in Germany" brand can still reach the world markets.
As welding technology plays a decisive roll for these companies, the entrepreneurs have to follow up the developments and innovations of the technologies which are useful for them. On one hand, the manufacturers for welding technologies continuously develop innovations thus providing opportunities to optimise the own production. But it is not always easy to choose the right solution for the own requirement from the multitude of offers. On the other hand, companies always demand new solutions because their requirements cannot be realised with the current technology.
Thus, for example, high tensile fine grain construction steels (S690 and higher) and stainless nickel-chrome steels are used more and more as well as normal construction steel (S235 or S355). Where lightweight design plays a significant role, aluminium materials and lightweight constructions become more and more interesting.
The metal machining industry also experiences immense versatility in terms of material thicknesses. While in some industries a 2 mm thick sheet is classified as thick sheet, other industries use 10 mm only for the type plates.
Thus, the metal machining industry offers numerous application possibilities and a major development potential for production engineering developments in general and in joining technology in particular.
Firstly, let's take a look at the mainly used welding processes. Secondly we look at the welding processes which, due to their technological advantages, are enjoying increasing popularity but are not yet so widely distributed. Individual examples of the automated use of robots with sensor application will also be presented.

2. Gas shielded metal arc welding (MIG/MAG)

The most widespread welding processes in the metal machining industries are the gas shielded metal arc (MIG/MAG) welding processes. Here we mainly differ between the classic arc types "short arc", "transitional arc" or "spray arc" and various "pulsed arcs". The classic arc types can be generated with simple step-switch machines whereas modern arcs mostly require digital controlled power sources. The advantages of these arcs include improved heat control and a safe and controlled drop separation at the end of the welding current pulse phase. This ensures that the drop is separated before the wire end can dip into the liquid melt. This would lead to short-circuits and therefore to serious spatter formation. The pulsed arc is well suited to a wide variety of welding tasks because it runs in a very stable manner and guarantees deep, safe penetration. It is used both manually and automated. With regard to the pulse control, most power source manufacturers incorporate an I/I control, in which both the pulse phase and the base current phase are current-controlled. Some manufacturers also offer a V/I control for pulsed arcs, in which the pulse phase is voltage-controlled and the base voltage phase is current-controlled. The picture shows the stylised form of a pulse process with the appropriate photos of a high-speed camera. The magnetic forces generated by the current separate the drop at the peak of the pulse phase before the wire end can dip into the liquid melt. Thus, there is no short circuit.



Picture 1: Current flow during pulsed arc welding

These arcs are even more stable and generate a deeper weld penetration, enabling further increases in the welding speed in many applications, or – mainly for manual applications – the countering of distance changes with insensitive arcs.

Modern power sources allow numerous process control variants. The Deutscher Verband für Schweißen und verwandte Verfahren (German Association for welding and related procedures) published the bulletin 0973 which lists the many different processes. A much discussed process is the modified spray arc. The power source regulation of this process produces a strong, short spray arc, with very high arc pressure. These features open new application areas. A high arc pressure causes an increased weld penetration and allows in addition welding with a longer stickout. This effect makes it possible to reduce the opening angle from, say, 45° to 40° (or even 35°), leading to significant potential savings in the layer count for each weld.

Overall, mainly the energy which is necessary for welding and the necessary filler material are considerably reduced. But there are physical limits which cause weld errors if the molten metal becomes too narrow.

Picture 2: Macrosection of a one-sided welding from the right at the T-joint with an opening angle of 30°.

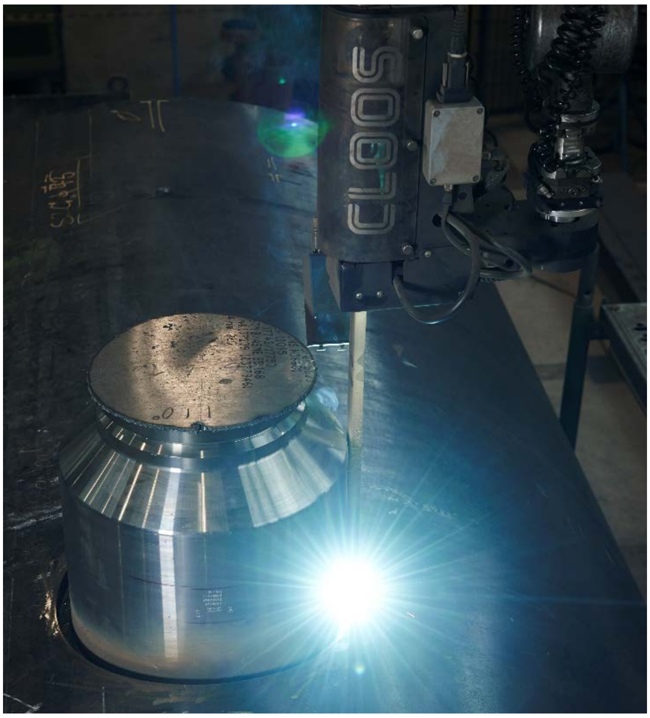
The high arc pressure also enables one-sided full-depth welding of sheets 6 mm thick with no single bevel preparation. This is mainly relevant from a corrosion point of view, because there is no remaining gap on the rear of the weld, which can offer an attack point for gap corrosion.

Gaps always play a decisive role during welding. That's why there are numerous welding processes at the market which were particularly developed to meet the requirements of the gap safety. For these applications the welders love to revert to the short arc. Only few energy is input in the component and the liquid melt can be controlled well. However, the short arc causes more spatters than a spray arc or a pulsed arc. For many reasons, spatters are not desired and mean extra work for the welder and thus extra costs . The new controlled short arcs are specialised on these requirements. The power sources control the short circuit resolution and reduce the spatters. Beside, the controls influence the arc stability. Particularly in the case of demanding tasks, as for example for

pipe constructions, there are high requirements to the weld seam and the welder. With the modern controlled arcs it is possible to control the liquid melt better and to avoid errors in the seam. This stability must not be lost even under changing circumstances of weld preparation.
In addition to the control possibilities of the power source, the process developers trust in further degrees of freedom. The possibility to feed the wire electrode opens completely new opportunities. Here the short circuit between wire electrode and liquid melt is not broken down in an explosion but interrupted by reversing it from the liquid melt. Thus the total process energy can be considerably reduced on one hand. On the other hand, there are nearly no spatters because of the short circuit resolution. Mainly processing of very thin plates (0.5-3 mm) or heat-sensitive material offers many advantages because there is less distortion than with the conventional short arc. However, these mechanically supported processes require additional component which must be integrated in the wire feed distance. Furthermore, the application is essentially restricted to the above mentioned plate thicknesses so that they are used most commonly in car body construction.
For applications with higher plate thicknesses or with particularly high requirements to the resistance to porosity, submerged-arc welding is the usual choice. After the determination of the correct parameters, the submerged arc welding process provides a secure weld connection and economic and high quality welding results due to its high deposition rate. As it is possible to weld with particularly thick wires and several wires, a deposition rate of more than 30 kg/hour can be reached which can be directly converted to welding speed in the case of suitable workpieces. It is easy to understand that a high welding speed increases productivity, because more material can be machined within a short time. Another effect of the high welding speed is the reduction of the heat input. This results in better material characteristics and less distortion which also reduces the expenditure for a subsequent straightening of the workpieces. The disadvantages of the submerged arc welding process include, however, a comparatively complex system construction, the powder feed and disposal as well as the fact that the welder cannot see the arc during production and therefore can only assess any irregularities in the seam only on seeing the result of the welding.
If need be, Tandem welding offers an alternative to submerged arc welding. Again in this case – this time via two melting wire electrodes - a passable deposition rate of up to 25 kg/hour is achieved This can be implemented on one hand in welding speed. This again reduces the heat input and leads to the desired minor distortion in welding. With current Tandem technology, welding speeds beyond 4500 mm/min can be achieved in the sheet thickness range from 3.5 to 4 mm. This equates approximately to heat input provided below 1.7 kJ/cm.
For areas with greater material thicknesses, the Tandem process can be used to increase the throat thicknesses of each layer and thus reduce the number of layers per weld. This result can be used to increase the efficiency.

Picture 3: Tandem robot compact system for manufacturing conical beams for ship drives

If material thicknesses greater than 35 mm are welded together, for example when connecting tripod segments or for big power station components, the use of narrow gap technology can lead to enormous improvements in efficiency. In narrow gap technology, the seam preparation opening angle is reduced to approx. 1° which also reduces the seam volume to be filled considerably. Accordingly, less layers are needed; less weld metal is produced as well, which means less heat input in the component thus minimising the distortion due to weld shrinkage.

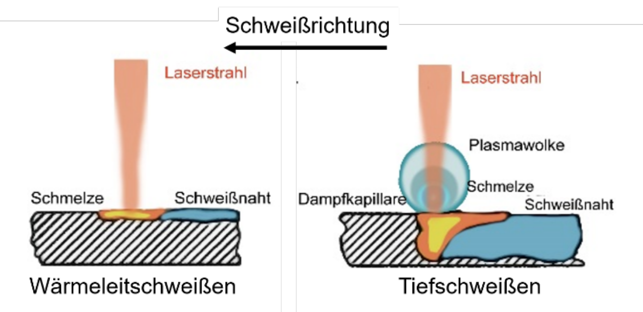


Picture 4: Macrosection of a narrow gap weld for reducing the opening angle

The extreme reduction of the material to be welded also influences the energy efficiency during welding. The savings are also made with other processes with reduced opening angle, but this effect is the biggest in the case of narrow gap welding for good reason.

3. Laser And Laser MIG/MAG Hybrid Technology

The different laser processes also belong to the efficient welding processes. Fundamentally, users can choose between the two process variants thermal conduction and deep welding for joining.

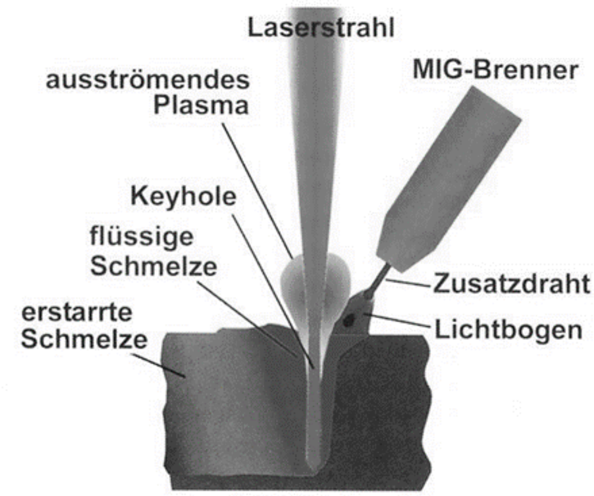


Picture 5: Diagram of laser thermal conduction and laser deep welding

Normally, the selection of the correct technology depends on the material thickness, the base material or the welding capacity. Thermal conduction welding is well comparable to Tungsten Inert Gas (TIG) welding and is suitable for comparable applications. The arc melts the material locally and the edges are combined in the melt to form a clean, virtually spatter-free weld. Compared to a TIG weld, the heat-affected zone is considerably narrower. Much higher welding speeds are also possible which means that the input heat introduced, i.e. the heat input, can be significantly reduced. This is a considerable advantage particularly in the case of sensitive materials or referred to thermal distortion. This process can be used either with or without filler material. Depending on the material it is advisable to work with additional shielded gas or root protection as with TIG welding.

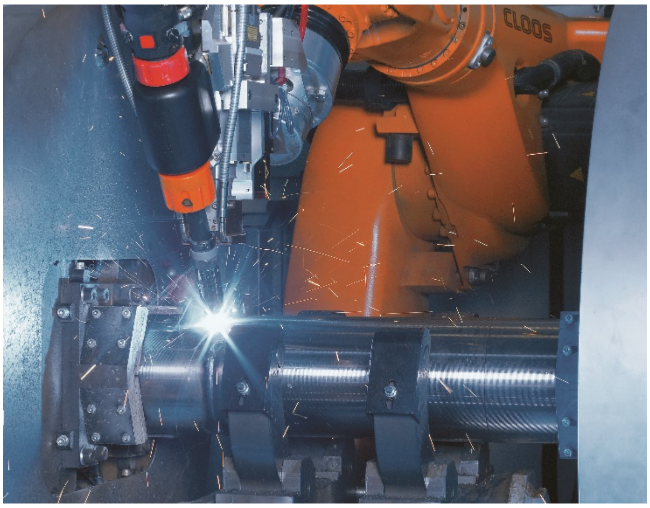
For larger material thicknesses, deep welding is an efficient alternative. In this variant of laser welding, the laser beam strikes the workpiece surface with a high energy density, melting the material locally and partially vaporising it. Thus a vapour capillary, the so-called keyhole, forms in the molten liquid which is maintained by the resultant metal plasma pressure. Inside this keyhole, the laser is repeatedly reflected and partially absorbed, thus enabling the keyhole to penetrate deeper into the material. With its high feed rate of the laser beam, the keyhole is driven through the material. The two edges melt together behind the keyhole and a narrow weld seam arises.

The process can be combined with a standard MIG/MAG process. This process combination is the laser beam MIG/MAG Hybrid process. Depending on the used laser, the laser power and the material, plate thicknesses of up to 20 mm can be welded in a single layer. As a rule of thumb, a laser power of around 1 kW is required for each millimetre of weld penetration in standard structural steel.



Picture 6: Diagram of Laser MIG/MAG Hybrid welding

The weld preparation in a V-shaped joint that is required for conventional welding processes is no longer necessary. This results in a considerable saving of weld preparation, the number of the layers to be welded, the filler material and the necessary welding time. And in addition the welding speed is significantly higher; in the case of laser welding it can be up to 5 times higher than with comparable MIG/MAG welding. The high welding speed has also the advantage that less heat is input into the component. In combination with considerably smaller weld volumes because of the narrow weld preparation, there is a much lower distortion than with comparable MIG/MAG welding. This also reduces the rework expenditure at components welded with laser and laser MIG/MAG Hybrid.



Picture 7: Laser beam MIG/MAG hybrid head for circular seam welding

To increase the efficiency of this process, further processes can also be combined with one another. It is conceivable, for example, to combine the laser MIG/MAG hybrid process with a Tandem torch downstream as well. This is how the laser hybrid head produces the necessary deep penetration and the Tandem torch fills up the joint completely with its high deposition rate.

4. Sensors support robot operations and automation

Most of the modern welding processes can be used both manually and automated. But often the high-capacity processes are only applicable for mechanised use. Regardless of this, the processes can only show their full strength during mechanised use. A manual welder is not able to reach the high wire feed and welding speeds. Due to the high flexibility of modern robot technology, robot systems can also be interesting for smaller companies.

Production processes can be automated easily, mainly by using sensor systems. Various sensor technologies can also be considered. Starting with simple arc sensors, which can find the centre of the weld using voltage changes and in this way track a weld, through tactile systems which contact the component and in this way, for example, detect the position of the component, up to laser sensors. There is a difference between laser sensors and off-line sensors – the latter find the weld before welding, measure it and correct the programmed robot track accordingly. Compared with off-line sensors, there are on-line sensors, which run up the welding torch directly and sample the seam. This allows not only to determine the precise position of the seam but, as with the off-line sensors, correct the robot track. On-line sensors can also measure the seam geometry and then take care that welding parameters are matched constantly during welding to the changing seam geometries. For example, if a seam during the welding process is getting narrow, the welding speed or power can be changed to prevent an inadmissible weld reinforcement.

5. Summary

Production engineering in Germany is now among the most powerful in the international competition. However, over-capacity worldwide is now placing German industry under cost and time pressure.

Consequently, knowledge of the various processes and their development progress is essential for a sensible selection of the correct welding process. Above all, high-performance processes and new process combinations are opening up new dimensions in production, the potential of which can influence a complete production environment. It is important to recognise that the component and the application provide the framework for the most suitable welding process.

Flexible production solutions guarantee efficiency for both major companies and small and

medium-sized businesses. From simple mechanization solutions all the way to complex robot solutions: flexible production systems and intelligently chosen welding processes shorten the cycle for products to be welded. Moreover, integrated solutions for mechanization and automation as well as modular automation solutions save costs on changing problems and improve production quality. This is how costly rework or complaints are avoided.
However, in the final analysis it is up to the user to assess which methods and processes are sensible for production and to prove them in practice. For this, the entire production process must be considered.