Application of Fiber Lasers to Pipeline Girth Welding

For the first time, it may be possible to use lasers for field welding of cross-country pipelines

BY CLAUS THOMY, THOMAS SEEFELD, FRANK VOLLERTSEN, AND EGINHARD VIETZ

Pipeline girth welding under field conditions has always faced severe demands with regard to quality and cost. Various manual, as well as partly or fully mechanized processes or a combination, are applied. The possible level of automation is determined by such criteria as material, dimension, intended purpose, and economic considerations. For steel pipelines, shielded metal arc welding (SMAW), flux cored arc welding (FCAW), and, most recently, gas metal arc (GMA) girth welding (partly or fully mechanized) are used.

Many of the welding machines used for pipeline construction around the world have not changed much over the past few decades. A diesel engine (usually air-cooled) is used to drive the welding generator (brush generator), which produces direct current (DC) of moderate quality. However, the problem is that cellulose-coated or basic electrodes for downhill welding used with SMAW only have thin coatings, and therefore are susceptible to current fluctuations. Moreover, if the open circuit voltage is too low, arc reignition may be difficult. Nonetheless, in many countries, pipelines are still welded with machines that are more than 30 years old — Fig. 1.

In those countries, wages hardly play a significant role in the calculation of pipeline construction costs. Moreover, financial considerations often gain priority over quality concerns. Consequently, modern welding techniques such as FCAW or GMAW are not widely used, and only recently have some welding machines been equipped with inverter technology.

The welding technique that still prevails in most applications is SMAW with covered electrodes. This process requires a large number of highly trained welders to achieve sufficient weld quality, which, especially in high-wage countries such as the United States, Germany, or Canada, is of substantial influence on the total cost for a pipelaying project.

A significant advancement was flux cored arc welding, which is used extensively nowadays by Chinese, Russian, and Indian pipeline construction companies. However, until recently it was only possible to weld fill and cap passes with this process. Moreover, with FCAW, the welders have to be particularly trained to closely maintain specifications. Its most significant drawback, as with all manual welding methods, is that the weld joint quality for each layer depends on the individual welder's skills, which may vary from day to day.

In order to lessen the influence of the individual welder on quality and to reduce the number of welders required, numerous efforts have been made since the 1970s to develop an automatic or semiautomatic welding method, mostly based on GMAW. The first in-field applications were reported from the construction of the "Drusba" pipeline from Russia into the former German Democratic Republic. Unfortunately, all attempts failed, mainly because the power source and control technology did not meet all demands. Nevertheless, the company VIETZ applied its first system at the end of the 1970s for a project in Denmark, where pipelines were laid in a tunnel crossing the Copenhagen harbor.

Nowadays, GMA girth welding has proved to be an economical welding method for pipeline construction — Fig. 2. There are different variations of the process, which are mainly chosen depending on the total length of the pipeline and the pipe dimensions. Considerations include investment costs, welding speed, and other economic aspects.

Currently, numerous systems are on the world market. Common to all systems are that several stations are required and that at least filling and capping passes are gas metal arc welded. They differ mainly in the technique applied for root welding, the degree of automation, the number of GMAW guns used simultaneously in one welding station, and the requirements associated with weld preparation and edge misalignment.

Aside from the necessity to stick to exactly prescribed conditions, all variants of orbital GMAW are technically fully developed. However, aside from repair rates in the range of 3–5% at best, the process has the disadvantage of being strongly af-

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Fig. 1 — Welding machine still in operation in Eastern Europe. (Photo courtesy of VIETZ GmbH.)

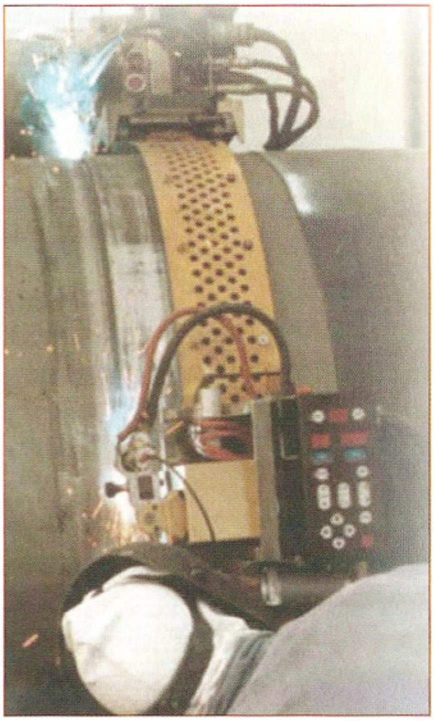

Fig. 2 — Gas metal arc girth welding equipment in operation. (Photo courtesy of VIETZ GmbH.)

fected by weather conditions and the operating personnel, who have to be highly qualified not only in the field of welding engineering, but also in electronics. Welding parameter controls, which affect the welding process in the different welding positions automatically, have the disadvantage that any changes in the welding conditions require quick intervention by the welder. Moreover, the relatively high investment costs for the required number of welding stations are an aspect that should not be neglected.

Consequently, a complete rethinking to achieve a further increase in performance and an improvement in quality was necessary. For this reason, the application of various laser systems to pipeline girth welding was considered in order to exploit their specific advantages.

Laser Sources for Land Pipeline Girth Welding

So far, laser beam welding has been successfully applied to the stationary production of (longitudinally welded) pipes (Refs. 1, 2). For girth welding, different laser welding techniques have been suggested.

Among the requirements associated with such systems for welding of land pipelines (for quality as well as for economic reasons) are the following:

- The welds should only be made from the outside.
- The beam source has to withstand vibrations and adverse environmental conditions.
- The beam has to be guided over a distance of approximately 30 m to the welding head.
- The power requirements may not exceed 160 kVA, because larger generator sets are difficult to handle on the construction site.
- The weld quality has to comply with the requirements.
- The welding speed has to be higher than for orbital GMAW.
- The investment costs have to be economically justifiable.

Consequently, both CO_2 and Nd:YAG lasers have to be ruled out because of energy and space requirements. They have in fact only been applied offshore or stationary, where such aspects are of less significance. The diode laser, which is in principle a mobile system, does not allow deep-penetration welding due to its low beam intensity. They require multilayer techniques for welding of thick-walled pipes.

However, recent developments in laser physics have made fiber lasers with beam powers exceeding 15 kW available to the market. This type of laser belongs to the solid-state laser group. Its laser active medium consists of an ytterbium-doped glass fiber that is optically pumped by means of diodes. The wavelength is 1.07 μm; its wall-plug efficiency may reach up to 30%. Additional information about the application of different high-power fiber laser systems for other uses can be gathered from Refs. 3–7.

The VPL System

The concept of the VPL system (Fig. 3) is to some extent based on the experiences gained in the context of the development of GMAW systems. Moreover, the specific characteristics of both the high-power fiber laser system as well as the requirements of the new welding process have to be taken into account.

The patent-pending system consists of an equipment rack and an air-conditioned chamber. The equipment rack contains the diesel power generator, shock-absorbent and air-conditioned mounting for the fiber laser, a chiller for the laser, the gas supply for the welding process, and all necessary systems for process monitoring and control. In a flexible tube package, the laser beam as well as all required assist media (such as process gas) are guided to the orbital welding head. An air-conditioned chamber comprises the orbital welding unit. It essentially consists of the orbital welding head adjustably mounted on an orbital guiding rail. The movement of the welding head relative to the joint is controlled by a sensor system. For penetration control, a plasma sensor is provided. Throughout welding, the pipes are aligned and clamped by a specially developed inner clamping tool.

Fig. 3 — The VIETZ pipeline laser (VPL) system. (Photo courtesy of VIETZ GmbH.)

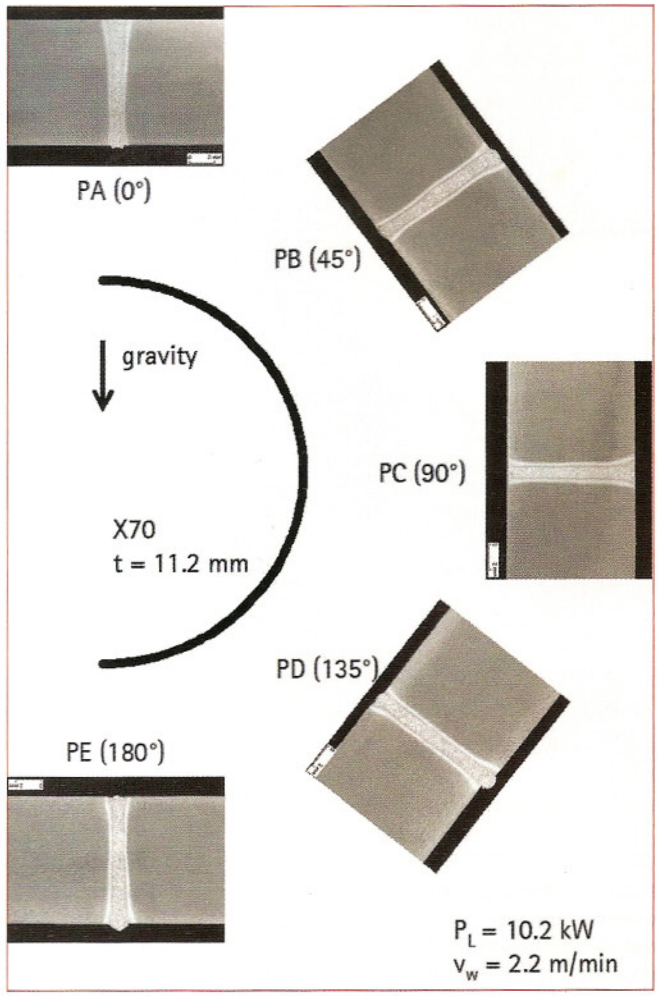

Fig. 4 — Pipeline steel X70, sheet thickness 11.2 mm, welding positions PA to PE, beam power 10.2 kW, welding speed 2.2 m/min. (Photo courtesy of BIAS GmbH.)

Results of Prequalification Trials

In order to prequalify the high-power fiber laser and the welding process for the specific task, BIAS has developed an all-position welding process for pipeline steels up to 16 mm thick. The basic requirement was to achieve a welding speed of at least 1.2 m/min, thus allowing welding of a standard pipe with a diameter of 1000 mm in approximately 3 min in one pass. Figure 4 shows welds obtained on plate material in a butt joint configuration (11.2-mm-thick X70 pipeline steel) for welding positions from PA (0 deg, flat) to PE (180 deg, overhead). Welding speed was 2.2 m/min for all welding positions; beam power at the workpiece was 10.2 kW.

All welds were extremely narrow and did not show any centerline cracks or pores, which was demonstrated by x-ray testing. Moreover, complete fusion and a sound root formation were always achieved. Due to the extremely small melt pool, the influence of gravity was rather limited and did not negatively affect joint quality and process stability.

Another aspect that has to be taken into account is that the pipeline materials of the X-type have a considerable potential for hardness increase and, consequently, low Charpy values for welding processes such as laser beam welding, which are characterized by very short t8/5 cooling times (typically below 1 s). To cope with this problem, a special time-temperature cycle has to be applied. It was demonstrated that, by applying appropriate preheating, it is possible to achieve t8/5 cooling times exceeding 7 s, which resulted in a significant reduction of the martensite content to 30% and below, resulting in a hardness of less than 260 HV 0.3, thus fulfilling the requirements of the applicable standards.

With these welding parameters, it is potentially feasible to join 1000-mm-diameter pipes with a wall thickness of 11.2 mm in approximately 1.5 min. However, by the application of fiber lasers with even higher beam powers, these limits might be pushed even further. Consequently, development continued applying a YLR-17000 fiber laser with a maximum beam power of 16.7 kW at the workpiece.

With this laser, it was demonstrated that X70 (sheet thickness 11.2 mm) can be joined with a beam power of 15 kW at a speed of 2.8 m/min. Figure 5 (left) shows a cross section.

This joint was again characterized by a rather narrow cross section, complete fusion, and a sound weld bead appearance. X-ray testing demonstrated that no relevant cracks or pores existed. A small edge misalignment of 0.3 mm was easily bridged.

However, under field conditions, edge misalignments exceeding 1 mm have to be faced. Consequently, without special parameter optimization, trial welds assessing the influence of edge misalignment were carried out — Fig. 5. Without any loss in welding speed, considering root formation, edge misalignments up to 1.4 mm could be bridged. However, to compensate for weld sinkage, it is recommended to apply either hybrid laser-GMA welding or a GMAW cap pass.

The results from these studies were then used for girth welding trials of tack-welded pipe segments from X70 (800 mm diameter, wall thickness 12 mm) under laboratory conditions — Fig. 6.

These trials demonstrated that with a beam power of 15 kW and a welding speed of 2.3 m/min, pipe segments can indeed be joined up to edge misalignments of 1.5 mm. Moreover, it was established that the direction of welding (uphill/downhill) does not significantly influence weld quality.

Summary and Outlook

To improve both quality and cost situation in the construction of land pipelines, a high-power fiber laser welding system was designed. Due to the unique features of the high-power fiber laser, this system has the potential to bring laser welding of pipelines for the first time into the field.

For prequalification, the laser system

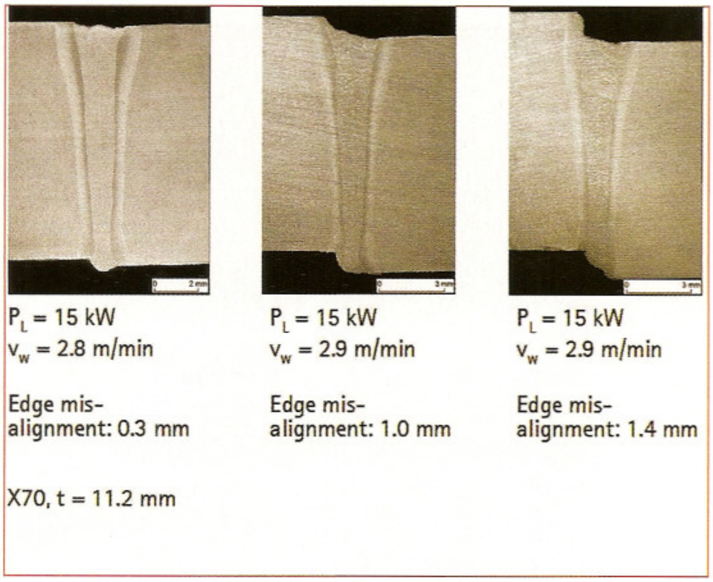

Fig. 5 — Pipeline steel X70, sheet thickness 11.2 mm, welding position PA, beam power 15 kW, welding speed 2.8 m/min. (Photo courtesy of BIAS GmbH.)

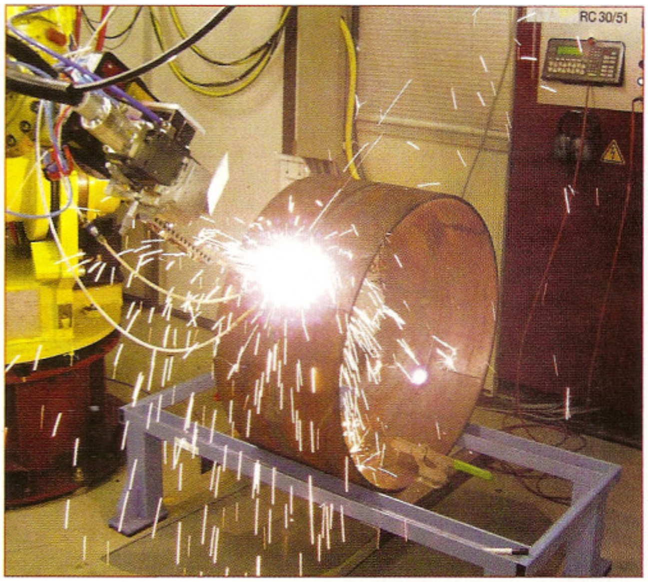

Fig. 6 — Girth welding of pipe segments with the fiber laser YLR-17000. (Photo courtesy of BIAS GmbH.)

and the welding process have been developed and tested under laboratory conditions. It was established that the process is, in principle, capable of fulfilling all associated requirements, and especially that pipeline segments of X70 (thickness 12 mm) could be welded in one layer at a welding speed of 2.3 m/min.◆

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