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ELECTRON BEAM WELDING OF GEAR WHEELS BY SPLITTED BEAM

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Abstract

This contribution deals with the issue of electron beam welding of high-accurate gear wheels composed of a spur gearing and fluted shaft joined with a face weld for automotive industry. Both parts made of the high-strength low-alloy steel are welded in the condition after final machining and heat treatment, performed by case hardening, whereas it is required that the run-out in the critical point of weldment after welding, i. e. after the final operation, would be 0.04 mm max..

In case of common welding procedure, cracks were formed in the weld, initiated by spiking in the weld root. Crack formation was prevented by the use of an interlocking joint with a rounded recess and suitable welding parameters, eliminating crack initiation by spiking in the weld root.

Minimisation of the welding distortions was achieved by the application of tack welding with simultaneous splitting of one beam into two parts in the opposite sections of circumferential face weld attained on the principle of a new system of controlled deflection with digital scanning of the beam.

This welding procedure assured that the weldment temperature after welding would not be higher than 400 °C.

Thus, this procedure allowed achieving the final run-outs in the critical point of gear-wheels within the maximum range up to 0.04 mm, which is acceptable for the given application.

Accurate optical measurements did not reveal any changes in the teeth dimensions.

Key words

electron beam welding, beam deflection system

INTRODUCTION

The most recent research in the field of welding technology and development of new systems for beam control allow applying the electron beam welding in the cases of just hardly or absolutely unsolvable problems of material weldability and/or welding parts for extreme

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applications. One of such cases is the welding of gear wheels made of high-strength materials, where welding necessitates extreme accuracy at the maintained perfect soundness of fabricated welds.

Owing to its priorities, the electron beam welding has been applied already for half a century for joining, as a final production operation in the manufacture of gear wheels, mainly for transport means. The applied standard procedures allow such manufacture with favourable economic merits.

However, the ever increasing demands bring about more or less extreme requirements for their joining. This is mainly the case of the manufacture of aircraft engines, but also of cars with extreme demands. One of such cases, where the entire part cannot be made of one piece, is the welding of spur gear with hypoid gearing (Gleason) with a hollow fluted shaft with extremely high demands on production accuracy, applied mainly for 4 x 4 drives (Fig. 1).

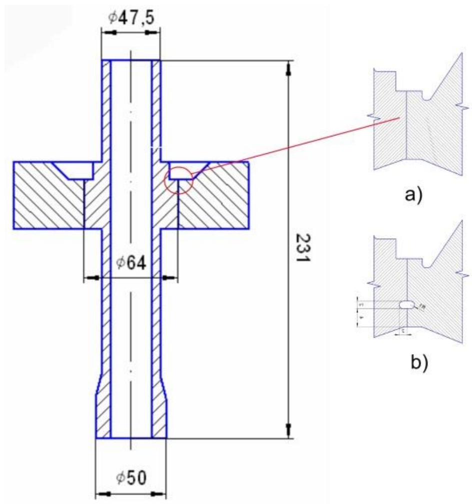

Fig. 1 *Welded part of car axle drive*
a) weld joint initial design, b) weld joint new design

MATERIALS AND METHODOLOGY OF EXPERIMENT

The joint distortions could not be eliminated to desirable level in the first tests, neither by pressing the parts in the joint location, nor by tack welding with individual tacks along the weld circumference. Though the tack welds have a fixing effect, these may also cause distortions due to the fact that they exert principally the same distortion effect, though in a lesser measure than the weld. Since the gradual tack welding with individual tacks on circumferential weld is always eccentric (away from the geometric axis of weldment) it would cause asymmetric stresses and distortions at any weldment restraint, which can be hardly balanced by welding the after solidification of tacks, whereas this condition gets usually even worse.

Therefore, we applied a new developed system of electron beam splitting into several beams for tack welding. This allows multi-position acting of beam by the simultaneous process of its digital scanning. It is based on the principle of short time acting of the deflected sharply focused beam on the desired point, followed by an extremely fast shift to another point so that the acting of these beams in the given point is actually instantaneous, regarding the thermal inertia of material heating.

The system of programmable electron beam deflection consists of a magnetic deflecting coil and the electronics control system. The deflection process is controlled from a technological computer, controlling the course generators via communication through a USB port. Enter of the deflection profiles is enabled through a utility program operating in several modes given by actual requirements. The designed system is capable to deflect the electron beam in two mutually normal X, Y axes within ± 7° range. The deflecting system makes possible either static beam deflection (± 7°) or dynamic beam deflection. To degas the weldpool, low amplitude beam oscillations with the frequency from 0 to 20 kHz are used. Trajectories of the oscillations are programable. The system enables also programmable planar energy distribution of the beam power for the surface thermal treatment applications (Fig. 2) and beam splitting to several beams for the purposes of distortion-free welding.

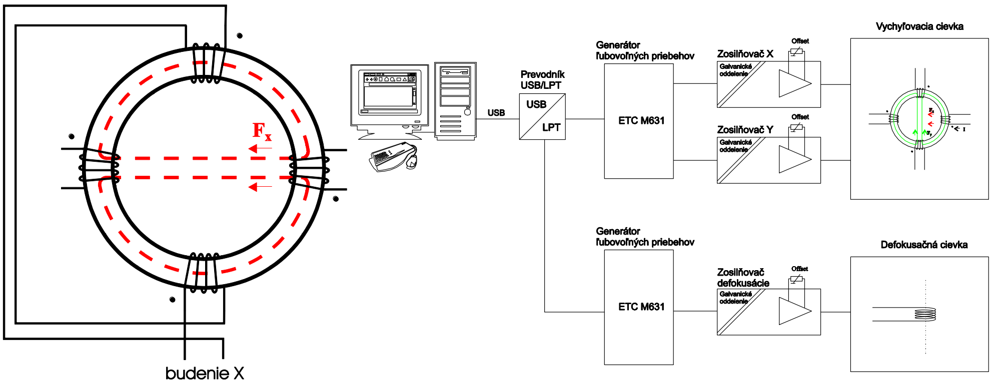

Fig. 2 *Electrical connection of deflection coils and block diagram of computer control of deflection system*

By a fast step-wise transfer between two points and repeating return, we obtain the splitting of the main beam into two beams capable to weld in both points in the same instant. The time of beam dwelling in each point must be sufficiently long to cause the material fusion, and at the same time sufficiently short to prevent solidification of the weld pool in the point which is just not exposed. In this way, it is even possible to attain several beams that may be used for simultaneous welding in several points and/or welding in one point and heating (with a slight defocusing) in other points (Fig. 3).

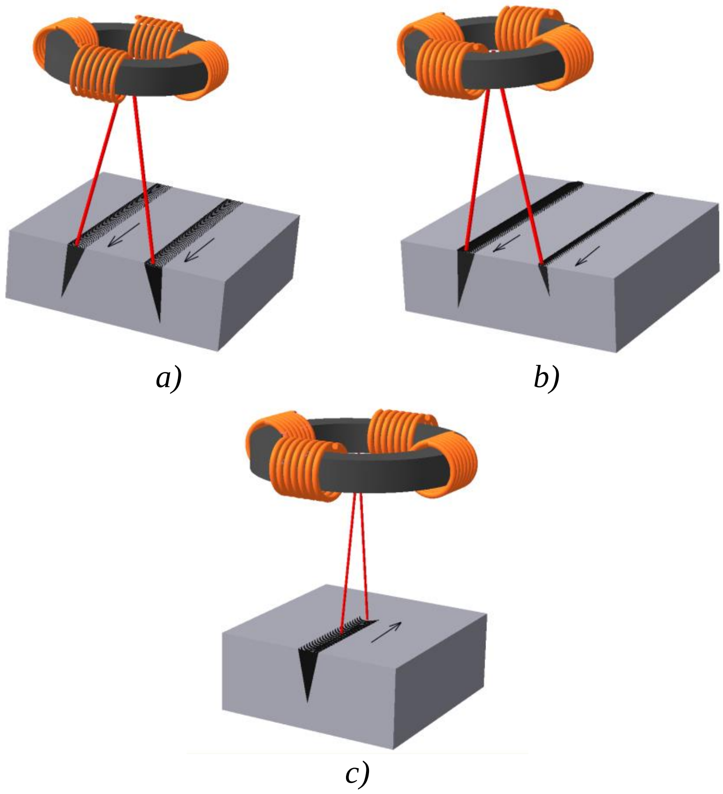

Fig. 3 *Examples of simultaneous acting of a beam on several points by its splitting into several beams a) with the same power, b) with different power, c) acting with two beams with the same focusing in tandem position*

We can create a macro for each specific case in MS-Excel program, which helps us to form data files for the beam trajectories in X, Y axes and for defocusing. This allows controllable feeding of the deflecting and focusing coils of optical beam system of electron canon, with deflection angle 70, controlled by a generator of standard courses as sine, cosine, saw, triangle, rectangle and circle which are pre-defined and it is possible to generate also the courses created by user on his PC screen with a mouse.

The dimension of the scanned beam area, as X, Y system, is 256 x 256 points. Beam power in these points is given by its dwell time in the given point, i.e. by the number of time samples. In this way, it is possible to create any 2D shapes and also third dimension may be obtained by the beam dwell in a given point, i. e. by the control of heat input volume. This allows a multitude of variant solutions, for example surface heat treatment, surfacing and welding simultaneously with several beams in single operation, preheat, post weld heat treatment etc.

ATTAINED RESULTS

Welding procedure consists of tack welding process and welding process. The beam splitting for tack welding was achieved by deflection system scanning. The electron beam was spit into two positions for tack welding. After the weldment rotation by 90^{o}, this tack welding was repeated and a four-position tack weld was thus fabricated. Weldment was rotated during tack welding, and therefore individual tack welds were around 10 mm long (Fig. 4).

The following welding parameters were used for tack welding with beam split into two parts with the same power:
Voltage: 55 kV
Current: 15 mA
Speed: 9.5 mm.s^{-1}.

Welding was then performed with a single beam with the following welding parameters:
Voltage: 55 kV
Current: 35 mA
Speed: 9.5 mm.s^{-1}.

The run-out distortions were measured during tack welding and final welding by an accurate deviation meter. The results of these measurements are shown in Table 1.

Five identical pieces fabricated by this procedure were tested by the customer who assessed them as fully acceptable, regarding both, joint soundness and welding distortions. These results allow welding of a greater series of parts for car manufacturing.

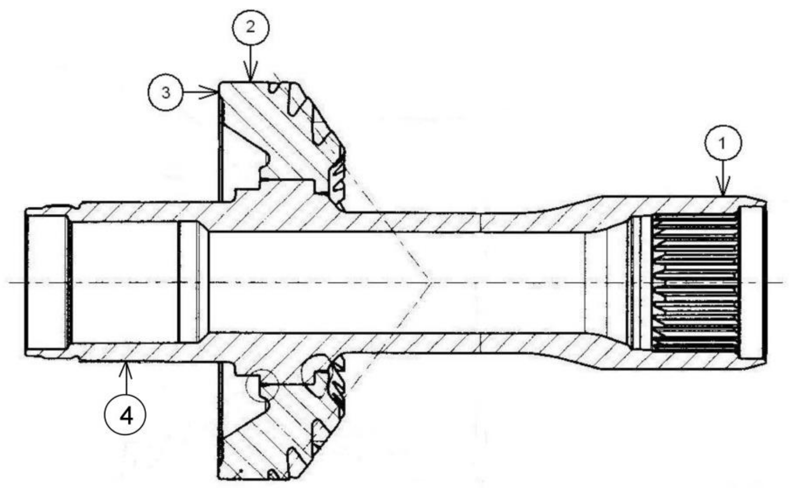

Fig. 4 *Weld part with marked points of run-/out measurement*

RESULTS OF RUN-OUT MEASUREMENT ON WELDMENTS BY DATA COMPARISON FOR ONE OF WELDMENTS Table 1

	Run-out deviations prior to welding [mm]			**Run-out deviations after welding [mm]**			**Difference in values prior to and after welding [mm]**		
Points of measurement									
Welded part	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
1	0.08	0.08	0.03	0.04	0.07	0.06	- 0.04	- 0.01	0.03
2	0.06	0.06	0.04	0.07	0.06	0.07	0.01	0.00	0.03
3	0.04	0.03	0.03	0.03	0.04	0.03	- 0.01	0.01	0.00
4	0.06	0.08	0.03	0.06	0.06	0.02	0.00	- 0.02	- 0.01
5	0.07	0.06	0.02	0.03	0.01	0.05	0.01	- 0.05	+ 0.03

DISCUSSION

Welding, i. e. application of full power parameters for fabrication of a weld over entire welded thickness with several beams simultaneously did not prove to be suitable for the given solution. This was caused mainly by the problems with formation of end craters on a circumferential weld and by beam skewing against the weld plane, what may result in side lacks of fusion.

Problems with suppressing distortions were therefore solved by the application of simultaneous tack welding, employing the described procedure. Since the tack weld has a low penetration depth at the rounded root without spiking, only the minimum end crater is formed, which is in addition overlapped by subsequent welding. It could be supposed, that the effect of such tack welding, with the aim to minimise the welding distortions, would be sufficient for the weldment fixation.

Owing to practical reasons, a two-fold beam splitting was selected, performed on mutually opposite points of the face circumferential weld. This allowed suppressing the greatest distortions of circumferential welds caused by thermal-strain effect of welding start at the eccentric position against the neutral axis of the weld.

CONCLUSION

Application of electron beam welding in the manufacture of highly demanding products, as for example high-accurate gear wheels, often require a sophisticated approach, both to design solution of the joint and also to welding technology. The most recent development in the field of control and distribution of the beam, resulting in the form of multi-beam welding process, allows solving also the technologically intricate problems, as presented in this contribution.

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