Design and optimization of laser welding technology for automotive seat belt sensor

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Abstract

The laser plastic welding is a new technology making permanent joints, which brings a lot advantages over conventional welding technologies. It is a physical method of welding, which means that heat is used and it is generated by the interaction of a laser beam with a welded material. Advantages of this prospective technology were taken in the cooperation with TRW Carr Ltd. Company. We proposed technology specifications which could be used in the prototype production at first and then in the large-scale production. The cooperation with our department was based on drafting positions and shapes of welding for different component rotations. The next aim was to find suitable welding parameters for solid-state laser, a comparison with other types of lasers, and then a selection of the most appropriate equipment for this welding application. After testing methodology, there was proposed and recommended some further operational tests. And finally, our department provided a support for the TRW Carr Company at the beginning of technology, which means to give advice on optimizing of laser welding and also to test welds produced on prototype devices.

Keywords

Laser, Welding, TRW, RCMT, CTU, Plastics, Seat belts

1. Introduction

The conventional press-technology of the sensor housing to the sensor cap was replaced by the laser welding housing sensor to the sensor board.

Verification of the laser welding technology for this application was necessary to perform from the welding process base to the optimization of the welding parameters.

The research of the laser plastic welding was an order and therefore all the results cannot be published.

2. Reasons for choosing the laser welding technology

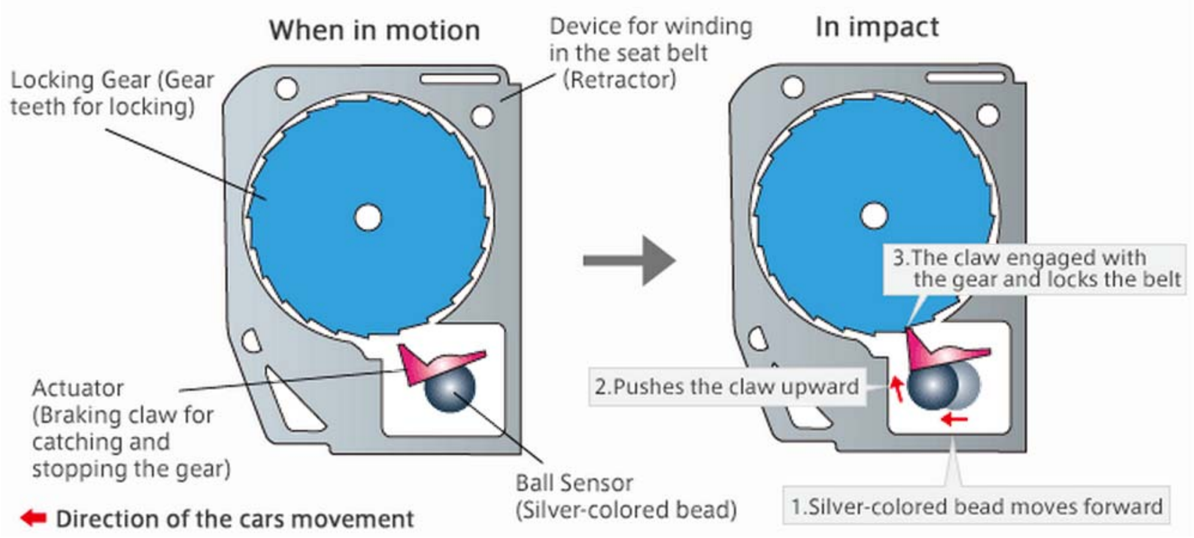
The laser plastic welding is a new technology based on creating permanent joints, which bring a lot advantages over conventional welding technologies. It is a physical method of welding, which means that heat is used and it is generated by the interaction of a laser beam with a welded material. Welding is performed by the pressure, which is deduced by external clamping force.

An advantage of the laser welding technology is a possibility to weld materials without any other additional materials. The laser welds usually have good visual characteristics in a wide spectrum of conventional and modern thermoplastics. Another advantage of this technology is a possibility to use it in extremely demanding applications, such as thin-walled components or extreme process speeds. All of these benefits contribute to the achievement of high-quality joints in all welding positions.

The modern laser welding technology of thermoplastic materials is convenient for the high-speed process realizations and for the compliance with appropriate quality welds. Welding, in this case, is very fast, accurate and with almost no waste of materials. The result of the welding is that the weld is almost invisible by seeing it by the eye. Compared to conventional welding methods, the laser welding allows the connection materials with good quality and with very little degradation of their properties. Due to the high energy concentration of the laser beam, the material melts for a very short time which prevents from overheating and degradation. Another advantage is a possibility of sensitive welding control, which means we can achieve precisely defined conditions for making a high-quality weld. Productivity of the laser welding is quite large, therefore automation is convenient. All of these benefits contribute to the achievement of high-quality joints in all welding positions.

The issue of placing the sensor in the sensor board is very extensive, but in a simplified form, a correct position of the sensor with relation to the gravitational acceleration is needed.
This technology enables a positioning of the sensor in the sensor board in any ways and also a subsequent locking by welding.

This technology can simplify the entire production, so there is no need of a wide range of sensor clamps with different rotation angles; everything is implemented by using one universal shape. Laser welding is simplified, but mainly, the cost of production is lower.



Obr. 1. *The fiction principle of the seat belt sensor* [7]

3. Technology proposal

Factors entering into the process belong are constructions of welded components, their material and requirements on the rotation. It is necessary to provide the required joint strength achieved by the overlapped weld joint. Specific options of laser welding, which allow welding components at contact point, are also decisive, due to the passing of the laser beam through a plastic sensor board.

3.1 Proposal of shapes and positions of the welds

With respect to this application, it is necessary to propose welds shapes and weld positions in a way to achieve a high-quality welding of components. Sufficient weld strength and guaranteed reparability of the process are required. Another factor is a accuracy of the placement and also minimizing the effects that adversely affected the strength or subsequent sensor functionality. *[1]*

Weld locations have been proposed at the all required positions, which will be implemented in the production. Furthermore, other 8 extreme sensor positions were suggested. The proposed limit positions have shown a variability of setting and they were used as a guide for other proposals of other functional positions. *[1]*

Analysis of weld placement consisted of the design of an appropriate location and of a design of the weld shape. For each sensor position in the sensor board was proposed a position and a shape of the weld in a way that the weld has enough space and also the size of the guaranteed strength enables the requirements of the weld. *[1]*

Weld locations were proposed as intersections of both welded surfaces. When proposing the position and size of the weld, the position of the sensor had to be taken into consideration, and therefore the suitable area for the location of the weld was smaller. *[1]*

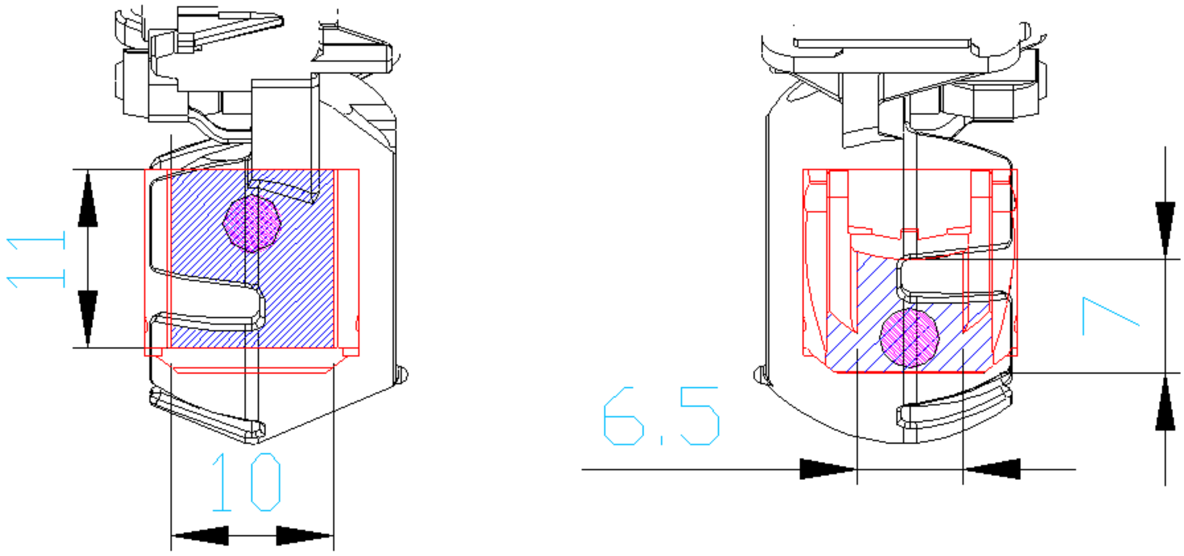


Fig. 2. *Intersection of overlap sensor surface and sensor boards suitable for welding*

In the Figure 2, the body sensor part is marked in black, the welded sensor part with in red and the intersections of the welded part in blue. These areas are suitable for the location of the welds. The future weld, which respects the requirements for welded parts, is marked in violet. The centre of gravity of the both welded areas was always determined. The centre of the weld was located into the determined centre of gravity. If the area was more diverse, the weld was located in a way, so its area was located into the intersection of the welded surfaces.

Welds positions was proposed for two welds modifications. The shapes of the first welds are lines in length of 3 and 6 mm. The strength of the weld is sufficient and the weld shape is more suitable for solid-state laser, but it is more demanding for CNC control and manipulation during welding.

The second weld profile is a circle with a defined diameter. This shape is realized by defocusing of laser beam and it is suitable for solid-state, as well as diode and fiber laser. The strength of welded joints is also adequate. The advantage is also a low demand on control and manipulation during welding.

3.2 Optimization technology by experiments on solid state lasers

The first welding tests were used to determine welding parameters. During welding by solid state laser of greater power, as it was in our case, a lower frequency is usually used. The most suitable frequency f_L was intended to 30 Hz. The pulse width t_L determined appropriately to the number of pulses per second and it was intended to 7 μs. In combination with the size of the pulse energy, the output power P_L was obtained from the values of the frequency and the pulse length. The maximum power was 50 W. *[2]*

In the first welding test, the parts were matched to each other, clamped in a vice and the sensor position was set manually. The components were clamped in a way that the welded area was perpendicular to the laser beam. The laser beam was focused on the surface of welded components. This concept was sufficient for obtaining basic welding experience of components on the solid-state laser. For welding from both sides, it was necessary to clamp parts twice. *[3]*

First of all, welds of line shapes were welded; the lines were placed onto the proposed positions. During setting shape, the focus was used between welded components and speed so great to match the time required for welding. For the time of 0.5 s, different movement speed vp were used for each side specifically 12 mm/s and 6 mm/s. *[2]*

Ten welds were welded by using different times of laser exposure. The strength of weld joing was sufficient and it was not possible to break the welds off by hand. The times of laser exposure were suggested from 0.2 s to 1 s. *[2]*

After welding the components in the zero position of the shaped welds, a series of circle welds was welded by using a stationary beam. The beam diameter was achieved by defocusing the beam about +20 mm of the Z axis when using the welding lens of 120 mm. To guarantee the point size when using the unfocused beam, setting of the optical set should be given. In this case, the setting was: 540/630. Other parameters are unchanged in relation to the programmed tracks. *[2]*

3.3 Technology optimization on diode lasers

Welding was carried out in a positioning jig, in which the components were clamped. The total laser power was 40 W. The weld was made in a shape of line and circle. *[3]*

When implementing the shape of lines, the focus between the welded parts and speed was used big enough, so the time for welding could correspond. The speeds of 10 mm/s and 5 mm/s were used for the time of 0.6 s. The speeds of 12 mm/s and 6 mm/s were used for the time of 0.5 s. *[3]*

The beam diameter of the circle shape was achieved by defocusing of the beam of the Z axis and by using the welding lens with a defined focal length.

The short focal length and shape of the positioning jig did not allow using a perpendicular laser beam with the welded area. Misalignment of the beam was 12°, but we expect that the misalignment affected the welding process just a little bit. *[3]*

Beam could be perpendicular to the welded surfaces when using a stationary defocused beam due to a defocusing distance.

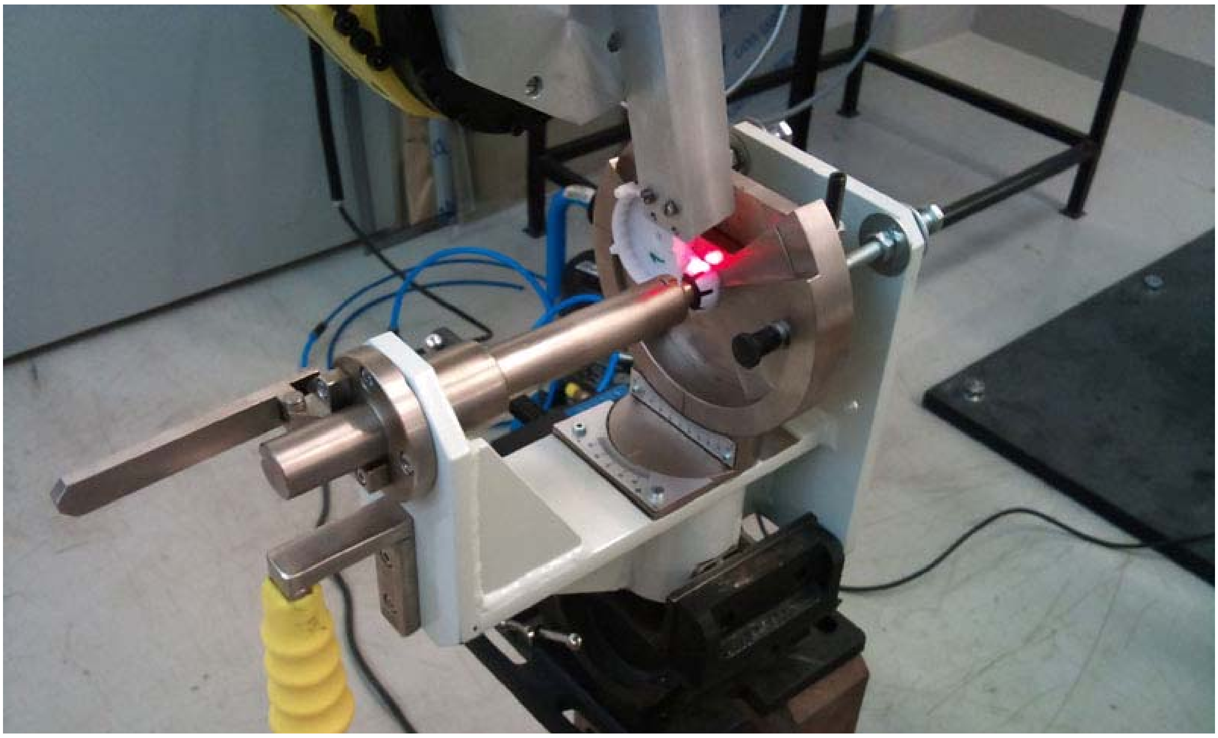


Fig. 3. *Component establishment during welding on diode laser*

3.4 Comparison of different laser types for this application

Welding tests were carried out in various types of lasers. For this application four lasers were selected: solid-state laser, fiber laser, CO2 laser and diode laser. Several components were welded by each laser and by using different parameters. Welds varied in shapes, which was either a circle or a line. Furthermore, the time of the laser exposure was different too. It ranged from 0.3 s to 1 s. *[3]*

All the necessary criteria for producing high-quality welds were met when welding on solid-state lasers. Solid state laser design is however more complicated; it has low efficiency and it is necessary an intensive cooling during the process. Therefore it is not recommended for serial production. *[4]*

During welding on the fiber laser, sufficient strength welds were achieved and the laser is therefore suitable in this application. The high cost due to the advantages of the high precision of the laser beam is unnecessary, because the advantage of the beam quality is completely lost by defocusing the beam. For this reason, we do not recommend this type of laser. *[4]*

Welds made by CO_2 laser do not fulfill the requirements for the strength and therefore we do not recommend this type of laser for this application.

When welding by diode laser there were no undesirable effects, such as leaking of the material. The disadvantage is very low quality of the laser beam. Welds do not have the shape of a circle, but a shape of an ellipse. This effect only occurs when the beam is guided from the source by more than one fibers and when it is in the optical head folded back into a single laser beam. If the beam is kept by a single fiber, the weld has the shape of almost a circle. Generally, the beam ovality has no impact on the quality of the welds.

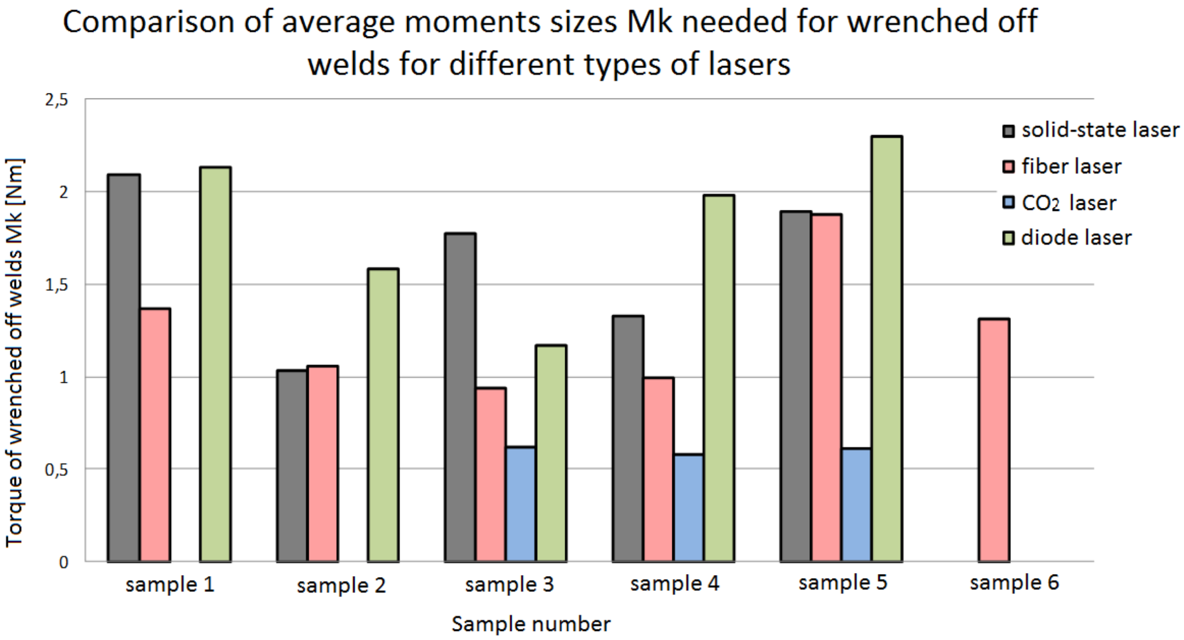


Fig. 4. *Comparison of sizes of the wrenched off moments for different types of lasers*

4. The welds properties testing

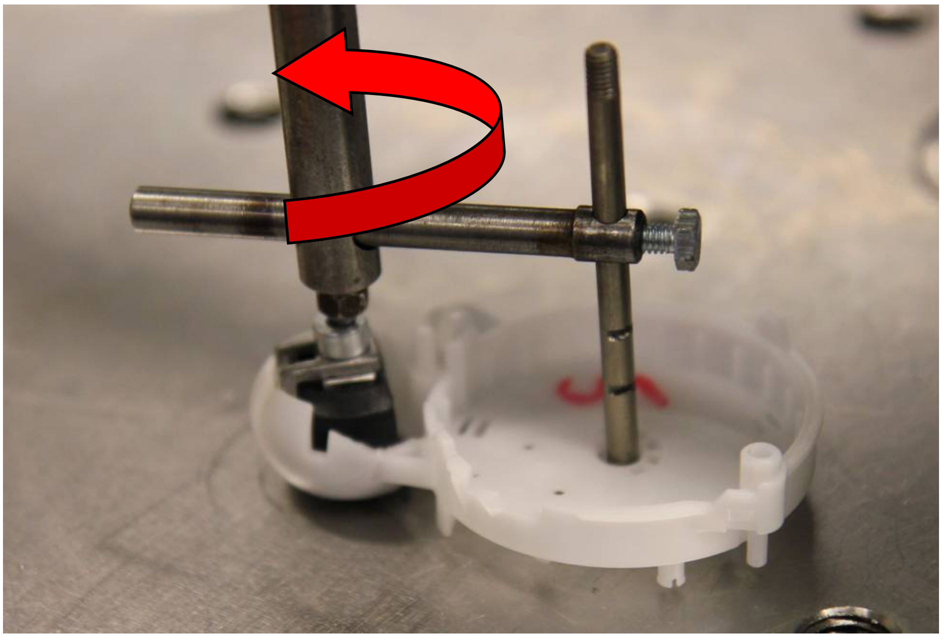
Because of large requirements of the process reparability and guarantee of solid joining, it is desirable to set the technology in order to achieve the best results and then continually test the parameters of the weld connections. For this purpose, control tests will be used. They will be probably carried out on the production line before starting a new set or in its progress.

Apart from a good strength in production, the weld has to endure throughout the life of the car and it has to resist all the external influences, which affect the weld. Operating tests will be used to test the strength influence throughout the life.

4.1 The welds strength testing

The basic requirement for a weld is its strength. The weld should be strong enough to be able to keep the sensor with the mechanism in the position, in which it was welded. A steel bar, which is a weight, causes the highest force onto the weld. There are also other forces affecting the weld, which are created by tension during welding or stress caused by temperature changes. Because of spherical anchoring of the sensor and welding it from both sides, there is only one way to break the weld off. It can be performed by slipping away. Other destructions depend on strong deformation of the sensor and the sensor board, because the force caused by the ball acts perpendicular onto the weld. *[5]*

Strength of welded samples was tested by using torsion torque on the dynamometer Kistler 9255B. The dynamometer has four piezoelectric sensors, in which the signal is created. The signal is led by a shielded cable to the amplifier and A/D converter.From here the converted and amplified signal is led to a laptop, where is software DynoWare. By using this software, we can save data and evaluate them. By using this software we can evaluate a size of magnitude torque of broken welds. *[4]*



Obr. 5. *Weld testing to torsional strength.*

When evaluating the torque, an average value of the zero deviation was taken from the linear part at first (see Figure 6). The deviation of zero value is caused by a parasitic charge on the piezoelectric sensors. It can be caused by stress or by heat load of the sensors and it is different for each measurement. *[4]*

The next step was to subtract the torque in which the welds were broken. The figure 6 shows the increase of the torque up to the first weld broke. After the first weld is broken, the relieving components, which affect a reduction of the jump load torque, will be measured. *[4]* The same evaluation approach is used also in the second weld. The only difference is that the measured signal was unstable in the second weld. It was probably caused by the fact that after breaking the second weld, the measuring system was unsteady due to the force. Therefore the last value of the torque in the second weld, which was linear in the course, was taken. *[4]*

Comparable values for all measured torques of the broken welds are obtained after deducting the average deviation value from the zero value of the resulting torque.
From the point of view of the measurement evaluation, the torque of the first broken weld is the most interesting for us, because after exceeding this value, the welded parts are partly destructed and therefore the welded assembly is devalued. *[4]*

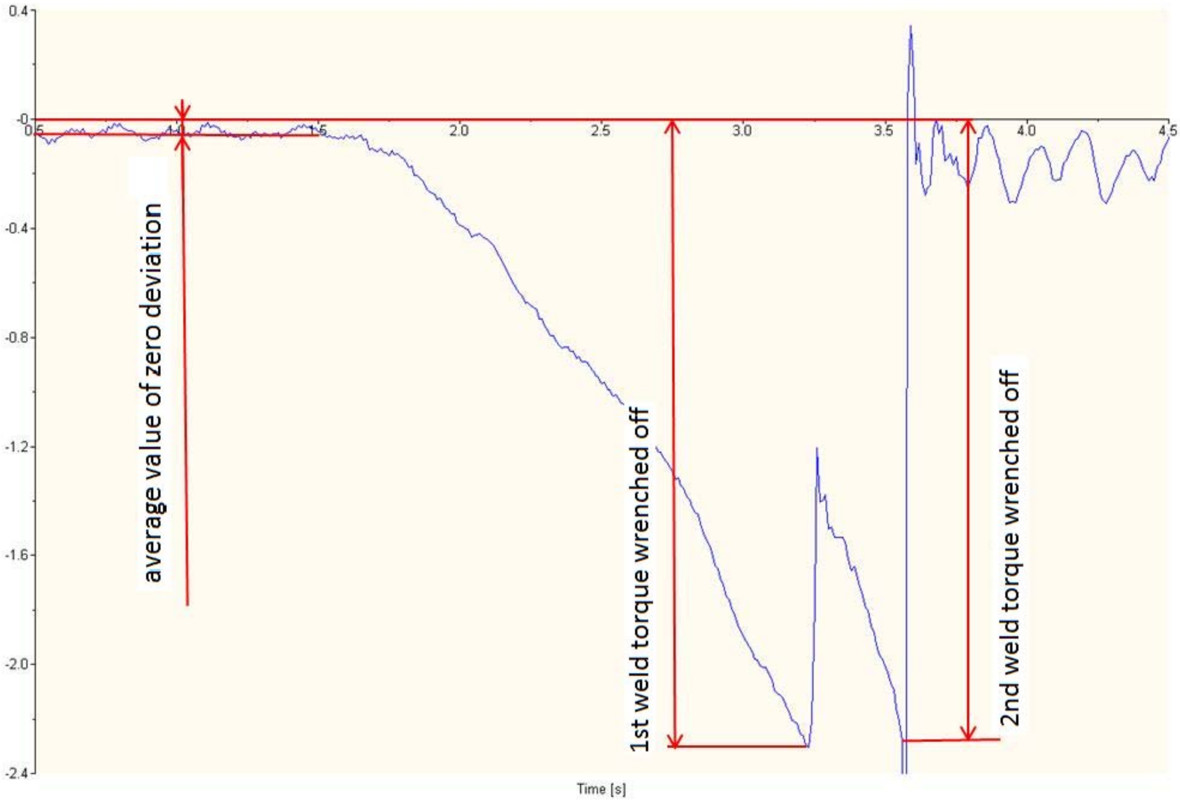


Fig. 6. *Scanned torque signal with a description of the evaluation.*

4.2 Tests of technology repeatability

One of the major requirements is a compliance of the process repeatability. The requirement of the reject rate separation is very big in this application. When requiring the reject rate in PPM, there are two ways to get to this value. The first option is to push the maximum representation strength to the right side towards to higher values. In a simplified way, it is an increase of the average measured weld strength in torsion. This way is easier; it is an improvement of welding technology for the specific type of laser to its maximum. Proposing laser parameters, such as the welding time or laser beam angle, by using the prescribed laser power in a way that the weld strength reaches the maximum value. The second option is a narrowing of the interval of the strength weld values. It is a reduction of the standard deviation values to the minimum values. This is performed by more accurate dimensional tolerances of the welded components. If the dimensions of the parts are in a smaller interval, the strength of the welded components increase slightly, but mainly the value of the measured weld strength becomes stable. Another way is monitoring of the laser power, welding temperature measurement and monitoring of the energy supplied to the weld pool. When ensuring the stability of these values, we also get more balanced results of strength welds. *[5]*

The original concept of welded parts, according to the indicators in the test repeatability for solid-state lasers, was not able to fulfill these requirements. In this test, the average value of torque Mk was only 1.07 Nm and there was a high value of the standard deviation, which was 0.40 Nm. There are several reasons. The original concept of welded components has a large contact area which did not include welds and geometrical tolerances ensure at these areas that they will be delayed from the welds area. Geometric tolerances can be reduced, but the inaccuracies will be always there, so the structural design with a smaller contact surface was desirable. *[6]*

When testing the technology, we increased the weld strength and also reduced the standard deviation of the measured weld strength.

4.3 Additional tests

As mentioned above, the weld has to endure and retain the sufficient strength for keeping the sensor in its position throughout the life of the car. The weld is loaded by a small force, but there is a large number of cycles. The force F is exerted by a weight which has approximately 4 g. Maximum number of cycles is in a range from 10^6 to 10^7. In such fatigue loading, it should be expected that mechanical and strength properties decrease. *[5]*

A major factor influencing the plastic welds and plastic degradation is generally oxygen or ozone influence. Additionally, if the weld has stresses, corrosion cracking occurs. The influence of degradation caused by environment should be eliminated to minimum due to the fact that the weld sensor and sensor boards are covered with a cap. *[5]*

Another factor influencing the weld throughout the life is temperature change. The car is exposed to weather conditions in which it has to resist the temperature changes, and therefore the weld has to resist these influences too. The weld has to retain a sufficient strength as well as to retain the strength throughout the lifetime, despite temperature changes through the whole year. Temperature loads can be in a range from -40° C to 90° C.

5. Conclusion

All the subtasks of the contract were fulfilled and we managed to produce a testing set of 125 pieces of products that had sufficient strength. The process repeatability was good and there was no piece which was out of the tolerance. After completing these tests, the production was transferred to the TRW Company, which purchased a new laser as a part of the prototype device. On this device, another set was tested and it met the internal regulations of the company.

After completion of these tests production was transferred to TRW company, where according to our specifications was purchased as a part of the laser device prototype. On this device was made another test series, which also complies with the internal regulations of the company.

List of symbols

f_L	*laser frequency*	(Hz)
t_L	*pulse width*	(μs)
P_L	*laser output power*	(W)
t	*welding time*	(s)
v_p	*beam velocity*	(mm·s^{-1})
Z	*the size of defocus focal point*	(mm)
L	*Weld length*	(mm)
F/R	*laser optics setting*	(1/1)
M_k	*torque*	(Nm)
F	*force exerted weight*	(N)
N	*maximum number of cycles*	(1)
T	*operating temperature*	(°C)

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