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Virtual clamping in automotive production line measurement

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ABSTRACT

Mechanical clamping of a production part in production line measurement causes numerous functional problems in automotive industry quality control. It kills flexibility and brings non-value adding costs. Being able to mathematically model the effect of clamping to the part, these problems could be overcome. Empirical research using statistical and 3D-analysis show, that the effect of mechanical clamping can be estimated accurately with a locally linear model using finite element analysis. The accuracy of this mathematical estimate is sufficient for production line use. Experiments, supported by Daimler AG, have been done using a production line measurement system. Using a mathematical model to estimate the behavior of the measured part while clamped is called virtual clamping.

1. Introduction

In the field of industrial quality control there is a considerable demand for accurate and flexible real-time optical 3D-measuring systems. The automotive industry is moving towards mass customization with growing flexibility and programmability in production lines. This raises the demand of flexibility and programmability also in quality control, especially in the on-line measuring systems. The technology for responding to this demand already exists and is operational in automotive industry. However, in most cases this opportunity for true flexibility in production line measurement is paralyzed due to the need of mechanical clamping of the production part during measurement.

1.1. Clamping in general

In the context of automotive industrial measurements clamping is a procedure where the measured part is forced from its natural form to fit a certain fixture, for example by clamping the part from its four corners to a plane.

When asking for the reasons for doing this we get on the ideological side of the issue. One fact is that in some cases automated mechanical measuring devices are not able to measure a production part if it is not forced to a known form and position. Yet, with state-of-the-art technology the mechanical clamping is not needed from the measurement point of view. On the contrary, in most cases it only causes problems.

Another ideology demanding for clamping states that the part must be measured in the same form in which it is assembled to the car chassis. Yet, this raises the question: which one does the bending, the part itself or the car chassis which it's bolted on? Of course both do have an effect on each other, but how much? Especially when thick rubber bushings are used between the part and car body to eliminate vibrations, which is a quite standard procedure, it is clear that the part will never be in the clamped form when installed.

Even if the clamping would distantly represent the situation where the part is bolted to the chassis, which it does not, we should ask if this is the only correct way to assemble cars. For example Daimler AG and BMW AG have quite the opposite construction philosophies. When the other philosophy states that the car body is rigid and the assembled parts deform according to the body, the other states that the car body deforms according to rigid parts. It is impossible to say which one is the right philosophy; both Mercedes's and BMW's are of high quality and very good to drive, even though in a different way.

Anyhow, when the designer has for one reason or the other marked a part to be measured clamped, for the part manufacturer this means that the part must be measured clamped, even though everybody in production and quality control agrees on that it is clearly the unjust way. Still, nobody is willing to take the responsibility to go against the definitions in the drawings. Changing the drawings of one part might end up as far as renewing approvals from officials for the complete car and rerunning all the testing. So if not for a technical reason, then for a bureaucratic and political reason a measuring system must too often have a clamp.

1.2. Motivation for the search of alternative solution

There are several reasons why a solution for this problem must be found. These reasons spread from economical to technical reasons, but they all state the same: a mechanical clamp does not fit

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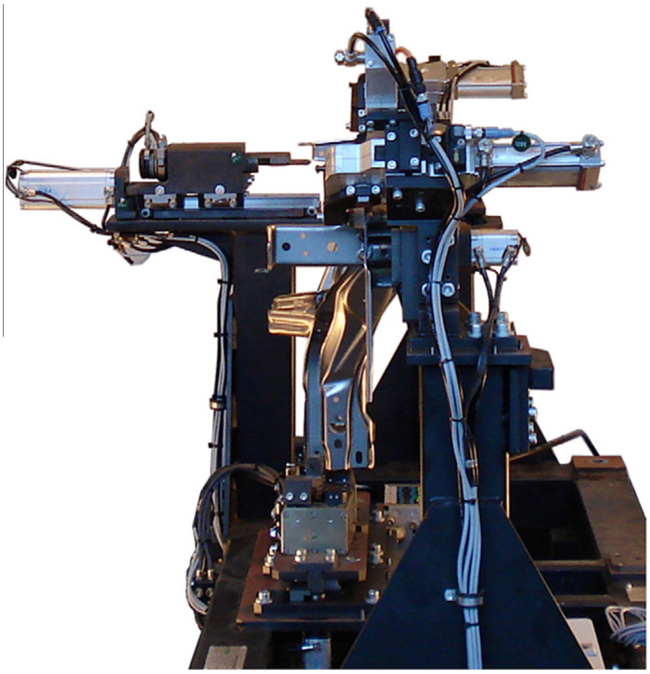

Fig. 1. Mechanical clamping device for VW Instrument Panel Support. The device weighs 300 kg, has eight pneumatic valves, a Siemens S7 PLC and costs 30 000 €.

to the picture of production line quality control anymore today or in the future.

1.2.1. Functioning problems of a mechanical clamping device

A mechanical clamping device requires moving parts to force the measured part to the required form. Moving mechanical parts require maintenance and spare parts, as well as are subject to malfunctioning. A mechanical clamping device also needs electricity, pneumatics or hydraulics to function. The control of a mechanical clamping device is relatively complex. Usually a PLC (Programmable Logic Controller) is applied. See a mechanical clamp used in automotive industry in Fig. 1.

1.2.2. Killing flexibility

A mechanical clamping device is always designed and custom made for one part or for a couple of quite similar variants at the most. This is a critical issue when there would be a need to produce smaller quantities but a greater number of different products and product variants on one but more flexible production line.

Similar kind of a situation occurs when the same measuring system could be used for several different production lines as a joint resource. In all cases part specific mechanical clamps are either showstoppers or at least great annoyances for any flexibility.

1.2.3. Changes to the measuring specifications

Modifying a mechanical clamping device after it has been built is mechanical and physical work and very difficult. The mechanical modifications of the clamping device are made inside the measuring system, where the clamping device is installed. Machining a heavy metal structure within a calibrated high-accuracy measuring system is unfavorable in every way.

Needs for modifying the clamping device occur all the time, especially in the pre-production stage, when there can be design changes in the measured part. Changes can occur also in the required points to be measured, robot gripper geometry, layout and so on. Most of these changes can occur also after the SOP (**s**tart of **p**roduction). In pre-production phase the costs consist mainly of the work and travelling. After the SOP also the cost of lost production must be comprised.

1.2.4. Non-value-adding costs

The structure of a mechanical clamping device must be very rigid and thus heavy to be able to handle clamping forces, say up to 5–10 kN, without noticeably deforming itself. Handling this kind of forces for several years in production line use means that every component as well as the entire mechanical structure must be of very high quality. Heavy structure with high quality components is always expensive. A mechanical clamping device used in automotive industry for clamping welded car parts costs commonly dozens of thousands of Euros. This means that somewhat fairly over a tenth or fifth of the cost of an entire installed measuring system might come from a device which has actually nothing to do with the measurement.

In addition to the manufacturing cost, all the above mentioned costs of modifying, maintaining etc. are added. So in a measurement point of view a mechanical clamping device is purely a considerable non-value-adding cost.

2. Composing the idea of Virtual Clamp

Clearly there is a conflict at hands if a production line has to be more flexible but still produce parts which have to be measured clamped. The only reasonable solution for this problematic equation would be if the clamping could be done immaterially, without any mechanical devices.

The idea of virtual clamping is rather simple. Instead of mechanically deforming the part, we do it mathematically. First we define how much the clamped areas of the part would be deformed from their natural form if clamped. Then we use this information to model how the part would deform globally.

The procedure goes as follows. The part is measured freely in its natural form. Then by knowing which points of the part would be clamped in the mechanical clamp it is easy to calculate how much this clamped point would move when clamped. An example of a simple (but very common) case: production part is defined to be clamped from its four corners to a plane. Fixing three corners to the nominal geometry and measuring how much the fourth corner deviates from the nominal geometry, we result in the amount of deformation given to the part if clamped.

2.1. Basis for Virtual Clamp

Keeping the automotive industry as a framework it can be said that automatically produced serial production parts are very alike. The dimensions of this kind of a production part are roughly around one meter. The deformations caused by mechanical clamping are a few millimeters at maximum. While being interested in deformations of this magnitude (couple of millimeters in one meter), they are below the elastic limit. This can be proven by mechanical calculations.

For example, with a deformation of 1.5 mm on a 462 mm long tubular beam (d_o = 60 mm and t = 1.34 mm) whose one end is fixed, will cause a maximum normal stress of 133 MPa (Parnes, 2001). The dimensions are taken from the part which is studied later (see Section 3.1.1). The yield strength of a common structural steel (S355) is 355 MPa. Deformations of a part made of common structural steel would be within elastic and linear limit (133 MPa < 355 MPa).

Therefore relying on material science of metals, it can be assumed that the behavior of this kind of a production part is locally linear when slightly deformed. While the metal deforms within elastic limit, behavior can also be assumed to be analogous