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ASSEMBLING PROCESS OPTIMIZATION FOR CAR INDUSTRY

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Abstract
A new assembly plant development was started for assembling various car engine parts for some European car producers at the Alba Plant, Visteon Hungary Ltd., Székesfehérvár in 1999 and has been continuing so far in co-operation with the author and colleagues at the Department of Manufacturing Engineering, BUTE. Within the very strict and serious requirements and specifications some new ideas for optimising the current assembly process – has been tested and using in Bedford, Michigan, USA recently – was even set out for the development as part of a new assembly process in the Alba Plant. In this conference paper the author was to summarise some results of co-operation and the development achieved in optimising the assembling process in the (Ford/Toyota/Nissan and Honda parts supplier) Alba Plant, Visteon Hungary Ltd., Székesfehérvár.

Key words: crimping, fuel pressure regulator, assembly, car industry

1 INTRODUCTION

The demand of the dynamic global market for higher quality and lower cost products with shorter development lead-time has forced – not only the global but – local industries to focus on various new product development and production strategies.

A new assembly plant has been established for producing wide range of various car engine fuel pressure regulators (FPR) for some European car producers at the Alba Plant, Visteon Hungary Ltd., Székesfehérvár since 1999. The assembly development has been continuing so far in co-operation with the author and the Department of Manufacturing Engineering. BUTE.

All variants of the "FPR assembly" contains 9 precision and corrosion resistant components among which there are drawn shells (made from chrome-nickel alloyed austenitic steels), springs (from wire ~ϕ0.1mm and ~ϕ3 mm) and ~0.2mm thick membranes (from textile fibres strengthened gum), polished ball and so. The final assembly (being composed within the final two process steps) consists of two sub-assemblies (housing sub-assembly, body sub-assembly) and two parts (retainer-spring and cover part).

2 ASSEMBLING PROCESS AND REQUIREMENTS

Depending on the FPR version ("flow-through" or "by-pass") being assembled the former or the latter sub-assembly is built up preliminary with using a lower level assembling block (valve sub-assembly) joined into the housing part or into a suitable body pre-sub-assembly.

The production volume and the very strict and serious quality requirements of the FPR assembly provided special specifications against the tooling:

– tooling designs should give consideration all brazed joints of the lower or upper half of the assembly
– all tooling had to support different part numbers (various design and embodiment of FPR assembly) with easy and quick changeover;
– using the same tooling for all part variants would have been ideal, but as it had not been feasible, 1-minute changeover from one part to the other was required;
– verification of correct setup had to be accomplished, no potential for setup error.

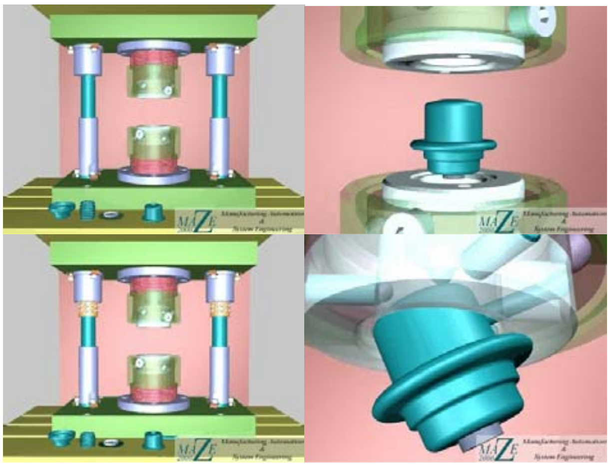


Figure 1 Components and the FPR assemblies of "by-pass" and "flow-through" versions with the crimping device before and after final crimping step (Solid Edge® model)

The original production process has been developed, tested and still using in Bedford (near Detroit), Michigan, USA even till now. The FPR assembling process – i.e. originally – has been defined containing five operations extended with preliminary oil-based lubrication – against the high range friction – and final washing – for removing lubricants before the very special and strict He-tests – operations so far.

The assembly process (e.g. for a "flow-through" type FPR) was specified as follows:

1. Polished ball and valve spring insertion into the valve (hereafter valve assembly). Option: press force indication.
2. Valve assembly pressed into the housing (hereafter housing assembly) Press in depth shall be controlled. Option: press force indication.
3. Retainer, two diaphragms and polished body pressed together (hereafter body assembly). The tool is a six point swaging tool. The press force shall be controlled. Data collection required.
4. 40° pre-crimp operation: The assembly contains the followings: Housing assembly, body assembly, spring and cover. Option: press force indication.

5. Final crimp: the previously pre-crimped housing assembly is flattened and the assembly process is finished. Press force versus displacement shall be controlled. Poke-yoke is required to prevent faults. Data collection required.

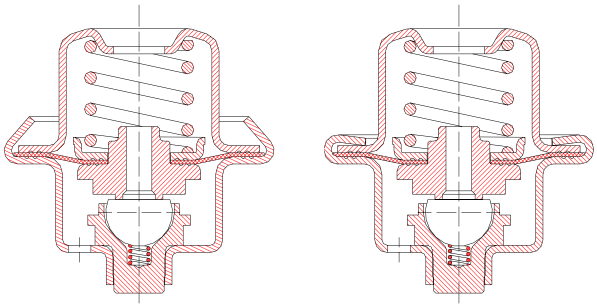


Figure 2. The FPR models after the assembling step 4 and 5: Pre- and Final crimping

The control parameters for both steps in that the membranes are fixed in the body- (step 3) and final assembly after crimping (step 5): the diaphragm squeeze along the contact surfaces must be consistent (between 30-50%), where Ppk characteristic must be controlled. For illustration the strict requirements (beside some others) against the FPR assembly and assembling process the cross-sections (prepared for squeeze control) of the body-assembly and crimped flange can be seen on the pictures below.

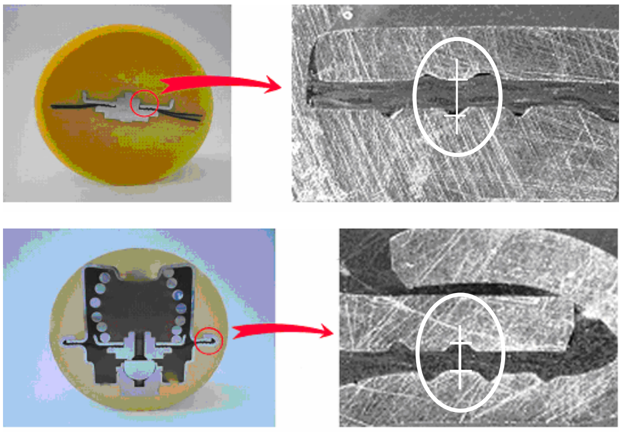


Figure 3 Control of the compressed diaphragm squeeze in the FPR body- and final (crimped) assembly

These requirements allow not more than 60μm tolerance field for the final crimping operation results on pressed diaphragm. Because of this and that the crimping provides / requires the biggest forming deformation among all the assembling operations, the most problematic steps of the assembling process are the crimping operations (Figure 5) for closing the entire FPR assembly. The problems are as follows:

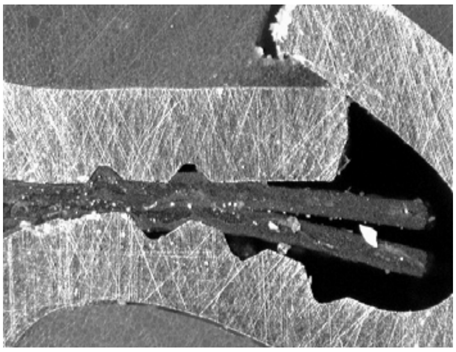


Figure 4 Fault effect of material sticking

- stick-slip effect between the upper crimping tool and the austenitic material of the lower housing assembly;
- following emergent and increasing sticking materials layer on the forming surface of the crimping tool;
- therefore, rather sensible crimping results to the tribologic circumstance.
- special attention should be sentenced to the tool wear, and against the huge friction lubrication had been applied;

however,

- too much lubricant can absorb the He from the air and cause false rejections on the final He-based crimp leak tester (functional control of the FPR).
- 40° pre-crimp and final crimp operations required within the previously pre-crimped body assembly is flattened for finishing the assembly process (left in Figure 5);
- despite of the two-step crimping process, too much torsion occurred in the bottom flat (middle in Figure 5);

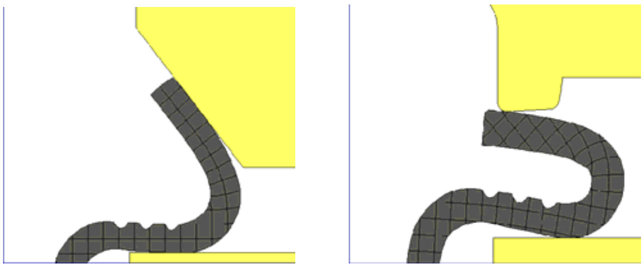


Figure 5 First (pre-crimp) and second (final crimp) step of the two-step crimping process analysed by Q-Form®

3 DEVELOPMENT OF ONE-STEP CRIMPING PROFILE

Over and above the requirements, some new ideas for optimising the assembly process was even set out for the development as part of a new process plan in the Alba Plant, Visteon Ltd., Székesfehérvár. Special considerations for the tool development were claimed and the goals of the author were:

- to combine pre- and final-crimp operations into one, to develop optimal profile for a one-step crimping tool (Figure 6), over and above, or following in fact;
- to make lubrication neglectful or cancelled by special coating of the forming surface to avoid crucial He absorbing.;
- to propose suitable manufacturing technique(s) for the more complex but one-step crimping profile in the future tooling specifications.

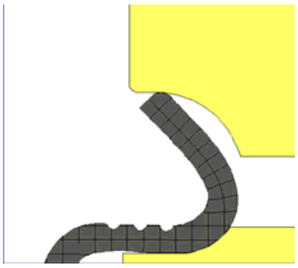


Figure 6 One-step crimping process in the view of Q-Form®

For these purposes the initial analysis and experiments have been applied. Based on the initial results a new geometric model and a numeric profile of a one-step tool were developed with using the Maple system. The numeric profile was optimised and analysed for avoiding material sticking.

3.1 Short issue of the initial analysis

The initial analysis of stress- and strain emerging in the housing part had been made with the help of the Plane CAE$^{\copyright}$ system based on SLM (Boór, F., Kardos, K. 2000). Meanwhile the real stress-rates and the global deformation process caused by the original “Bedford” tools and by a torus-profiled virtual tool had been analysed by the Qform$^{\copyright}$ and AutoForge$^{\copyright}$ finite element systems. The results of initial analyses showed that

- for avoiding stick-slip effect during the crimping procedure the adhesive static Coulomb-friction coefficient should be kept under 0,15-0.2.
- in the first phase of the process the crimping force-distance diagram shows local maximum point, which is approximately 45 kN. It can be called as the point of topple over, where the danger of adhesive material sticking can be critical;
- in the case of applying torus-profiles with different radii the local force maximum remained constant and independent from the entering contact angle with the profile;
- the maximal load was proportional to the initial (entering) slant angle and to the current (actual) contact angle between the crimping wall and the tool surface;
- the smaller initial contact angle is applied the position of local maximum was wandering to bigger distances.

3.2 Technical issues of pre–analysis and –experiments

The results of initial analysis and the fact that the experimental profile determined by the simple outline (geometric torus-shape surface) of the FPR design lead to material sticking effect in case of one-step process (Boór, F. 2001), therefore

- numeric profile, determined by the kinematics and the dynamic contact pressure-distribution while the crimped flange edge is wandering along the forming surface – controlled contact angle –, is required for avoiding stick-slip effect and too high local tip in the crimping force-distance diagram.
- dry (without applying lubrication) crimping can only be possible within such a strict tribology condition (with achieving so small adhesive friction coefficient) which can be produced by only high (ultra-) precise machining (polishing) and special coating on the forming surface layer.
- special metallurgical tool substrate material (with more than 60HRc) and low-friction thin-layer coating is suggested (substrate material: metallurgical high-speed steel – with medium or high rate tempering degree – or metallurgical (wolfram-) carbide material; coating: PVD WC/C “graphite” or TiAlN+WC/C “hardlube”).

3.3 The principals of computing numeric profiles

The Figure 7 shows the geometric model of the crimping process and the principles of the profile construction based on controlled and dynamic contact angle analysis. The basic idea of the contact angle control is illustrated below; e.g. to keep the contact angle constant to the profile curve moving down continuously while forming. The geometric criteria of this kinematical model led to a selectable partial differential equation system, which was – and since then has been – solved with the help of the MAPLE$^{\copyright}$ system.

Parallel with the experimental tests the computed numeric profiles were checked and optimised by the ADINA$^{\copyright}$ FE system for avoiding material sticking (Nyírő, J., Boór, F. 1999).

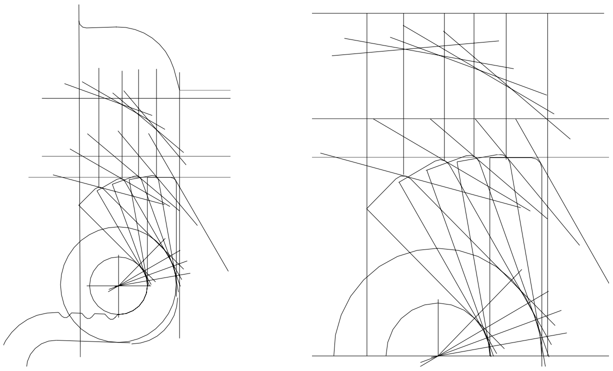
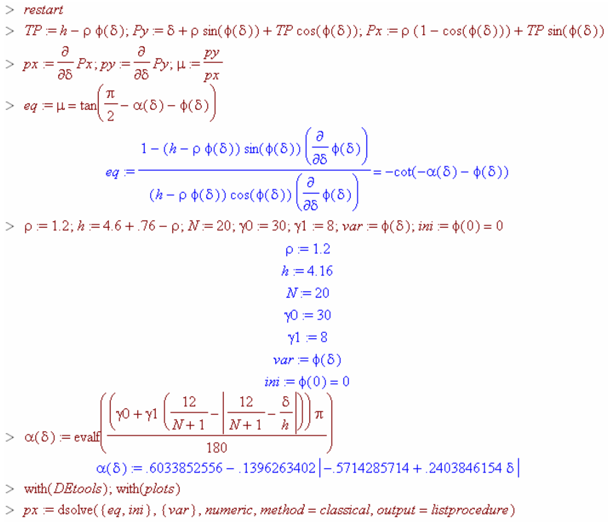


Figure 7 Kinematical model of process based on constant (controlled) contact angle

The Maple program is illustrated here below:



> $restart$

> $TP := h - \rho\,\phi(\delta);\ Py := \delta + \rho\sin(\phi(\delta)) + TP\cos(\phi(\delta));\ Px := \rho\,(1 - \cos(\phi(\delta))) + TP\sin(\phi(\delta))$

> $px := \frac{\partial}{\partial\delta} Px;\ py := \frac{\partial}{\partial\delta} Py;\ \mu := \frac{py}{px}$

> $eq := \mu = \tan\left(\frac{\pi}{2} - \alpha(\delta) - \phi(\delta)\right)$

$$eq := \frac{1 - (h - \rho\,\phi(\delta))\sin(\phi(\delta))\left(\frac{\partial}{\partial\delta}\phi(\delta)\right)}{(h - \rho\,\phi(\delta))\cos(\phi(\delta))\left(\frac{\partial}{\partial\delta}\phi(\delta)\right)} = -\cot(-\alpha(\delta) - \phi(\delta))$$

> $\rho := 1.2;\ h := 4.6 + .76 - \rho;\ N := 20;\ \gamma 0 := 30;\ \gamma 1 := 8;\ var := \phi(\delta);\ ini := \phi(0) = 0$

$$\rho := 1.2$$
$$h := 4.16$$
$$N := 20$$
$$\gamma 0 := 30$$
$$\gamma 1 := 8$$
$$var := \phi(\delta)$$
$$ini := \phi(0) = 0$$

> $\alpha(\delta) := \mathrm{evalf}\left(\frac{\left(\gamma 0 + \gamma 1\left(\frac{12}{N+1} - \left|\frac{12}{N+1} - \frac{\delta}{h}\right|\right)\right)\pi}{180}\right)$

$$\alpha(\delta) := .6033852556 - .1396263402\,\left|-.5714285714 + .2403846154\,\delta\right|$$

> $\mathrm{with}(DEtools);\ \mathrm{with}(plots)$

> $px := \mathrm{dsolve}(\{eq, ini\}, \{var\}, numeric, method = classical, output = listprocedure)$

4 FINAL EXPERIMENTS AND TESTS

4.1 Dimensional prove-out:

The tool tryout was performed at the press machine-tool supplier first and in the Alba Plant for testing full production capability and achievement. A verification of the tooling dimensions and tolerances, related to process/part specifications and interfacing systems or components, was conducted by the Alba Plant representatives once the machine is assembled and prior to tryout.

4.2 Dry run capability study

The tool was to run (dry cycle) for twenty (20) continuous hours, with the Alba Plant representatives present, prior to capability tryout. The Alba Plant was to accept the tooling after a successful eight-hour capability run had been achieved. The results of the dry run test can be summarised as follows:

- the experimental force-diagrams showed high stability and provided suitable load-curves for poke-yoke control to monitor and identify different kind faults (e.g. missing or more diaphragms, double crimping, feeding false piece, etc.)
- with using one step tools with an optimised profile (based on controlled contact angle), the contact pressure between the tool surface and the shaped material could be decreased, following the dry-technique became applicable without

coating in the one-step process (albeit with emergent thin chips peeling from the housing parts).

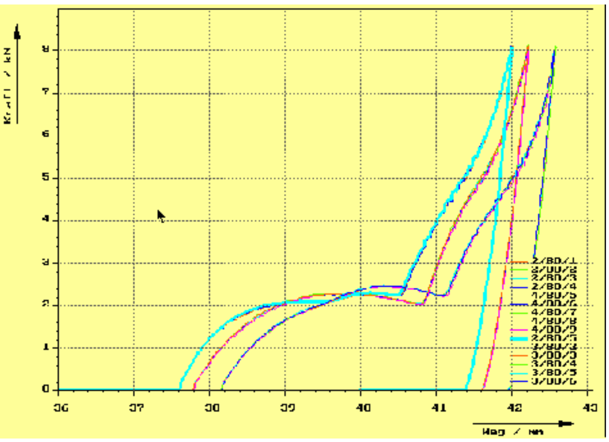


Figure 8 Force-distance diagrams provided by one-step tools with the test profiles No 2, 3 and 4 under the press load 80kN

- it has also already tested and proven that with applying proper (only 2-6 µm thick WC/C PVD) coating the dry one-step process can be sure managed successfully with respectable wearing-cycle (tool-life) of the crimping tool-insert.

Figure 9 Ultra precisely machined crimping tool inserts for PVD WC/C coating

4.3 Preliminary process capability study

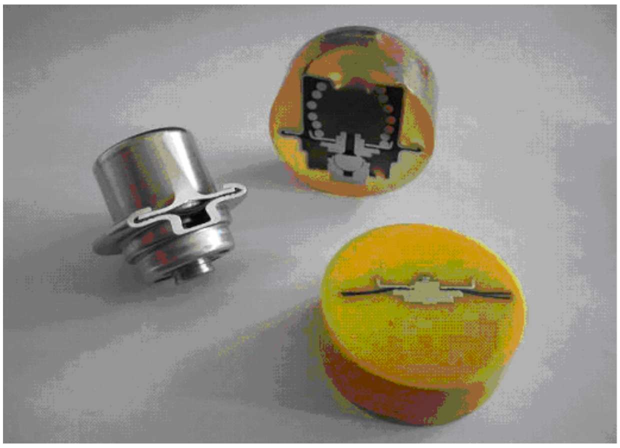


Figure 10 Test samples for process capability analysis

The capability of the tooling was determined by a 3-phase preliminary process capability study on all dimensions or parameters that had been considered significant or critical. These studies were conducted in three consecutive phases based on producing a 30-piece sample (phase I), a 125-piece sample (phase II) and a minimum of 25% subgroups over the 4-hour continuous run during machine acceptance runs (phase3). In every phase control charts was developed, where the subgroup size was the same as that used in production except the minimum requirement, which is 4.

The data collected were analyzed in accordance with the Fundamental Statistical Process Control Manual defined by Chrysler, Ford and General Motors. After process stability was achieved the Ppk data needed to yield a value of equal or greater than 1.67.

5 CONCLUSION

The membrane compression results of the one-step crimping in the preliminary process capability study can be seen in the Figure 11. The membrane squeeze field after the one-step process (right) meets requirements and considering its parallelism it is much more acceptable than the “Bedford” one used as reference part during the tryout.

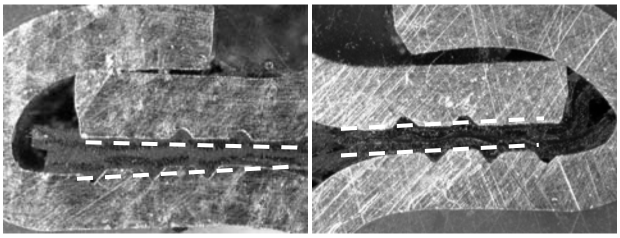


Figure 11 Diaphragm squeeze after “Bedford” (left) and “One-step” (right) crimping

However, with using one-step crimping tool-insert it was also issued that, the compression rates in case of the loads less than 70kN do not meet requirement and shows inhomogeneous (opening) characteristics such like the results of Bedford” (i.e. two-step) tools. On the other hand the loads exceeding 80kN can provide more homogeneous but higher compression rates than the limit.

6 ABOUT AUTHOR

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