The Effect of Manufacturing on the Press fit Insertion Force

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Abstract. In the automotive industry and not only, it is useful to have a very fast and simple assembly process between parts, so it is used the press fit process between parts. Usually, the press fit force depends on part geometry, radial interference between parts and material behavior. In this study was used one shaft (only one dimension) and thin sheet metal with different size of hole in order to have more interference values between parts. This work will present a comparison of the press fit force between the two types of manufacturing process (machining and blanking) of the hole in sheet metal. The numerical analysis is calibrated with the experimental measurement for machined hole in sheet metal.

1. Introduction

Because of the high productivity requirement, the press fits are used more and more in the assembly processes. Assembling by press fit belongs to the wider group of mechanical joining processes in the industry with high productivity.

The assembling by press fits is created by the differences in geometry of two mating parts, driven to the high contact pressure between the two surfaces in contact. This contact pressure holds the two parts in position after mounting and in service. The strength of this mounting is mainly depending by friction coefficient, interference value and contact surface.

This study is focused to find the difference between two geometries of the hole, one obtained by machining process and the other one obtained by blanking process. Because of the simplicity to obtain the machined part, the test is done for machined part.

In the press fit process are important the length of the contact, the Poisson effect and friction coefficient. The ratio between length and diameter of press fit has influence on Poisson effect, which mean for small ratio, the Poisson effects can be neglected but the friction coefficient is more important [1]. According to [1] [2], we can use the Lamé formula to calculate the pressure from contact:

\[ p = \frac{1}{2} \left( \frac{\delta}{b} \right) \frac{E_e}{E} \]

where:

\[ E_e = \frac{1}{E_o} \left( \frac{c^2 + b^2}{c^2 - b^2} \right) + \frac{1}{E_i} \left( \frac{b^2 + a^2}{b^2 - a^2} \right) \]
\[ F_i = \mu pA \]  

(Figure 1. Geometry of the press fit assembly parts)

with:
- \( p \) – contact pressure,
- \( \delta \) – radial interference value between parts, Figure 1,
- \( b \) – radius of interference, Figure 1,
- \( a \) – inner radius of inner cylinder, Figure 1,
- \( c \) – outer radius of outer cylinder, Figure 1,
- \( E_o \) – elastic modulus of outer cylinder,
- \( E_i \) – elastic modulus of inner cylinder,
- \( \vartheta_o \) – Poisson ratio of outer cylinder material,
- \( \vartheta_i \) – Poisson ratio of inner cylinder material,
- \( F_i \) – insertion force or friction force,
- \( \mu \) – friction coefficient,
- \( A \) – contact area.

According to the DIN 7190 [3] standard in the calculation of the interference must be taken into account the roughness of the surfaces in contact. The formula to calculate the interference is:

\[ U_w = U - 0.8(R_{zA} + R_{zI}) \]  

(4)

where:
- \( U_w \) – calculated interference
- \( U \) – interference
- \( R_{zA} \) – roughness of the hub
- \( R_{zI} \) – roughness of the shaft

In the [4], is modeled the roughness of the parts and considered in simulation by homogenized finite macro-element. For small interferences is useful to consider the roughness of the parts but for bigger interferences the asperities quickly became plastic and their behavior has relatively little influence on the average pressure.

The thermal stress and thermal expansion added over the assembly tightness can drive to the failure of the assembly. The alternates of the loads can have to be take care when is used the press fit assembly process [5].

2. Characterization of material
A tensile test using a “dog-bone” specimen was performed from cold-rolled electrical steel. The material is tested on 3 directions (Rolling Direction (RD), 45° from RD, Transversal Direction (TD)), at loading speed 5 mm/min which mean a strain rate around 0.0033 s⁻¹ on Instron 8874 testing machine at room temperature. The specimen tested has thickness of 0.65 mm with complete geometry presented in Figure 2.
3. The specimen “dog bone” and direction of specimen

The engineering stress – strain curves are presented in Figure 3. The data is used to calculate the press fit force, in numerical simulations.

The material used for sheet metal is anisotropic and has different properties on the rolling direction (RD) and transversal direction (TD). The characterization of the material for 45° from RD show a big value for tensile stress but less tensile strain at break. Yield stress for TD is with 5% bigger than the yield stress for RD and ultimate tensile stress for TD is with 3% bigger than ultimate tensile stress for RD.

In the numerical simulation an isotropic material was used, with the properties averaged from the 3 curves to have faster simulations results. In the further work the anisotropy of material will be considered.

3. Geometry for press fits

Below is presented the geometry used in the numerical analysis and in the test. The sheet metal has thickness 0.65 mm. The shaft material is stainless steel and has special geometry for one end to do more easily the press fit.
Figure 4. Drawing of the sheet metal

Figure 4 presents the geometry and dimensions of the sheet metal, used for tests and simulations. The dimension $\varnothing D$ from Figure 4 and Figure 5 has various value to obtain various tightness and the shaft has $\varnothing D=8 \text{ mm} \pm 0.005 \text{ mm}$.

Figure 5. Profile of the sheet metal

Figure 6. Scheme of the press in process

In Figure 6 it is represented the scheme of the press in process for assembly. We have the support (1), the sheet metal (2) and the shaft (3). The Figure 6a represent the press in process with the sheet metal profile machined on CNC machine (see Figure 5a) and the Figure 6b represent the press in process with the sheet metal profile made by blanking process (see Figure 5b).
4. Numerical simulations

Transient structural simulation was performed using Ansys Workbench 17.1 package. The 3D model was used in the simulation with higher order element type SOLID186 with 20 nodes/element, for all the parts.

It was compared the press force between the two profiles of the hole from the sheet metal, one machined hole (see Figure 5a) and the other one obtained by blanking (see Figure 5b). The diameter of the shaft has a constant value, but for the sheet metal hole more values were considered to obtain more values of the interference between parts.

The material models were linear for the shaft and support (E=210 GPa) and elastic-plastic bilinear for the sheet metal (yield strength =300 MPa and tangent modulus 864.4 MPa). The geometric parts were meshed in 15920 elements, around 71760 nodes for the sheet metal; in 27135 elements, around 114183 nodes for shaft and in 1944 elements, around 10512 nodes for support.

The support (1) from Figure 6 was considered fixed support like boundary condition. The symmetric behavior of the frictional contacts was considered between parts. The load was applied as displacement of shaft (1 mm) in the direction from the top surface of the sheet metal.

Our goal was to compare the profiles of the hole from sheet metal to understand the difference between them. In Figure 7 presents difference between machined profile and blanking profile hole. It is observed that the insertion force, in case of blanking profile, is lower than in case of machined profile hole.

The insertion force for profile machined has almost the same value when the interference is bigger than 0.010 mm. In case of blanking profile, the insertion force is increasing continuously until 0.030 mm interference.

![Insertion Force vs Interference](image)

**Figure 7.** Insertion Force vs. Interference (machined vs blanking)

Figure 8 presents the strain for machined profile with interference 0.01 mm /0.02 mm /0.03 mm on radius and in Figure 9 is shown the strain for blanking profile with interference 0.01 mm /0.02 mm /0.026 mm on radius. For blanking profile was used the maximum interference 0.026 mm because of the convergence issue. It can be observed the higher maximum strain in case of blanking profile. The strain for blanking sheet metal (see Figure 9) is 4 times bigger than the machined sheet metal (see Figure 8). The high strain appears do to the profile of the hole of sheet metal. The small amount of material is in “front of shaft” and high friction occurs on blanking hole of sheet metal on small surfaces.
5. Experimental investigation

The shaft used for the experiment is made of stainless steel and was polished on the surface which should be in contact with the sheet metal.

First measurement was done to determine the friction coefficient between shaft and sheet metal part. The most important is the friction coefficient on the axial shaft direction. The measurement was done with the system from Figure 10, the shaft was clamp between two half parts of sheet metal. The shaft was linked by wire over the pulley with the mass load. By knowing the mass which act on shaft and the loading mass the friction coefficient can be determinate. There were tests performed, one with cleaned parts (cleaned with alcohol) and other without clean the parts but without special lubricants. The results are presented in Table 1 together with the dry friction coefficient which was used in the numerical simulations.
Table 1. The friction coefficient.

| Friction coefficient | Partially Dry | Dry |
|----------------------|---------------|-----|
|                      | 0.4467        | 0.4975 |

The insertion tests were performed on machine Zwick Z005 at room temperature and constant speed of insertion 6 mm/min.

The maximum force obtained at 1 mm displacement was used to compare with the numerical simulation. The displacement of shaft was approximately 2 mm to insert the shaft until the cylindrical zone of the shaft (see Figure 12).

Figure 11. Typical insertion force vs. displacement of shaft

After 1 mm insertion either an increase or decreased of force was observed (see Figure 11). However, for comparison with simulation results only the load corresponding to 1 mm insertion was considered.

Figure 12. Insertion device and the shaft inserted in sheet metal

In Figure 13 can be observed a comparison of insertion force between measurements and simulations in case of machined profile of the hole from sheet metal. A very quickly increase of force at small interference has been observed, which means the material of sheet metal has a fast transition from elastic domain to the plastic domain.
6. Conclusion
The paper investigates the insertion force for two profiles of the hole, on machined and (see Figure 5a) and one named blanking (see Figure 5b). The total strain in the blanking profile case is approximately 4 times bigger than in the machined profile.

Prior to simulation the mechanical properties of the sheet metal were determined on three different directions. Also, the friction coefficient was determined experimentally in cases of partially dry and dry.

The insertion force of the shaft in sheet metal was measured in experimentally for the case of machined profile and was observed a good correlation between measurements and numerical simulations (see Figure 13). The insertion force is lower in case of blanking process than in the machined process.

7. References
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