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The influence of assembly clearance on the deformation and stress of an assembly structure through FEA simulation †

Ahmad Zia* and Lihong Qiao

Advanced Manufacturing Technology and Systems Research Center, Department of Industrial and Manufacturing Systems Engineering Beihang University, 37 Xueyuan Road, Haidian, Beijing, 100191, China

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Abstract

In order to facilitate parts assembly in a product structure, different clearances are provided in mating parts. The aim of this research is to investigate role of certain clearances in an assembly structure. These clearances are not part of tolerance stack but still can impart significant impact on product functional performance. Their influence on the product functional parameters like different stresses and deformation is studied in this research. A structure from automotive spot welding equipment is considered for this study. The effect of these clearances is determined using finite element analysis (FEA) simulations for process model of the product. It is found that some clearances are more critical for certain parameters. The results show that the product design can be improved by taking such clearances into consideration during design phase.

Keywords: Assembly clearance; Clearance analysis, Engineering design; Finite element analysis; Tolerance analysis

1. Introduction

It's a well-known fact that exact replicate component size is impossible to achieve through the manufacturing process. Therefore, a size range (tolerance) is an integral part of design activity. Tolerances are given on parts dimensions in order to avoid scrap while ensuring the required product function. These tolerances are directly linked with production cost, assembly, function, and manufacturability. Clearance is a type of tolerance which can be defined as a free and adjustable space between two mating surfaces that play a functional role in an assembly.

Excessive work has been done on tolerance analysis and different methods have been developed [1-4]. Moreover, tolerance analysis is part of different commercial CAD software at present as well as there are dedicated tools for this purpose [5]. The features of available software tools are described by Falgran [6] whereas classification and comparison of different tools is also presented in Ref. [7]. In tolerance analysis, accumulation of different variations on a geometric attribute of interest is examined; this geometric attribute can be a dimension, location and / or orientation [8]. The objective is to determine overall effect of different tolerances on the assembly performance requirements. The most common case of assembly tolerance analysis is the analysis of clearances in assemblies [7]. Generally, the purpose is to determine its role in tolerance stack analysis, assembly ease and space allowance for thermal expansion, etc. A particular dimension may be affected by several other dimensions, thus making a dimension chain. This dimension chain may include different components constituting an assembly along with their joint type. These dimension chains are also called 'dimension loops' and they can be 'open' or 'closed' depending on their configuration as defined by Lee [9].

Conversely, there are certain clearances which are not in a tolerance chain to influence product geometry in that sense but their value can still affect product functional performance to a considerable extent. These clearances are not given sufficient attention in literature as research focus is mostly on stacked tolerance analysis. Therefore, such clearances are identified and analyzed in this research, along with their relationship with different geometry instances and other product functional parameters. Furthermore, Guowei [10] identified that in conventional tolerance analysis, tolerance stack-ups in isolated conditions are analyzed and the practical conditions under which an assembly is required to undergo are not considered during analysis, resulting emergence of assembly errors under practical conditions. Therefore, it is very important to consider application scenario before finalizing the clearances and other dimensions. At present, CAD-CAE integrated solutions facilitate in considering application environment digitally for most of the application scenarios. Therefore, FEA based process

*Corresponding author. Tel.: +86 15501007007, Fax.: +86 010 82317735
E-mail address: ahmad1260@hotmail.com
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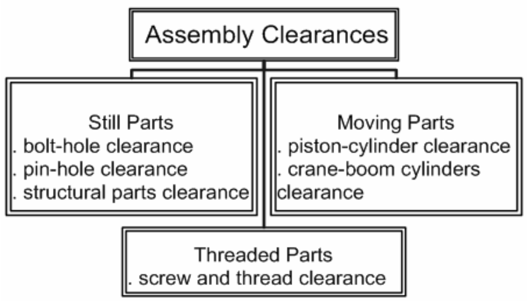

Fig. 1. Classification of assembly clearances.

model simulations are applied to examine role of these clearances on the assembly performance parameters. Generally for a product, process conditions are applied or induced loads, displacements, vibrations, temperature, etc. during product intended use. The product behavior under such process conditions is studied in this work.

The rest of the paper is organized as follows: in Section 2, problem formulation is described. In Section 3, simulation background and results pertaining to clearance effects on the product performance are presented. The conclusions are presented in Section 4. Next to that, the acknowledgement and references are given respectively.

2. Problem formulation

2.1 Types of assembly clearances

From application viewpoint, assembly clearances can be categorized into three major types as shown in Fig. 1; moving parts clearance, still parts clearance, and threaded parts clearance. Clearance in threaded parts is provided between threaded features of two mating parts in order to ensure their appropriate assembly e.g. screw-hole clearance. Moving parts clearance is also functional requirement between two moving bodies as only the presence of clearance can allow their relative motion e.g. shaft-bearing clearance, crane boom cylinders clearance, piston-cylinder clearance, clearance in mechanism joints, etc. An important aspect of this clearance is that it is enhanced with the passage of time due to wear and tear of moving parts involved. Different researches probe such form of clearance in the literature [11-14]. Still parts clearance is required to facilitate mating e.g. bolt-hole clearance, pin-hole clearance, clearance between structural parts, etc. [15-17]. Still parts are virtually still but there can be minor relative motion between them as a result of applied loading conditions. However, these are very small such as small displacement, deformation, bending, buckling, thermal expansion, etc. An application scenario having such clearance is under investigation in this research.

2.2 Arm assembly configuration model

Arm assembly is an important sub assembly in spot welding equipment for welding on automobile structures at automotive assembly line. The three major parts of concern in this assembly are arm, housing and support. Function of housing is to clamp arm, as well as provide threads for mating of support on it. Support function is the reinforcement of the arm while it goes under immense force during the process. The schematic diagram of arm assembly is shown in Fig. 2.

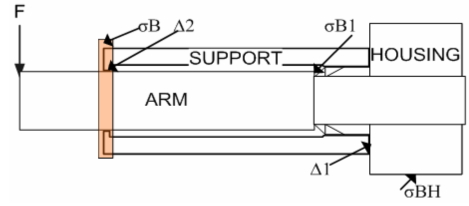

Fig. 2. Arm assembly schematic diagram.

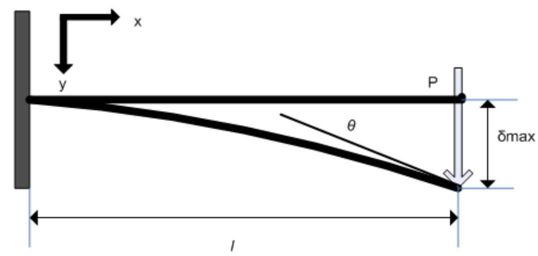

Fig. 3. A simple cantilever beam with deflection and slope.

Different stresses (σB, σB1 and σBH) important for this assembly are also shown in the same figure, these stress notations stand for max stress in Arm and Support in the shaded area, max stress in arm near housing, and max stress in housing respectively. The significant clearances under investigation are Δ1 and Δ2, representing face clearance between support and housing and radial clearance between support and arm in shaded area respectively. In arm assembly structural configuration, the arm is clamped at one end by housing and force is applied at the other end during the spot welding process, in its simplest form it is a case of cantilever beam as shown in the Fig. 3. The notations P, δ_{max} and θ represent the applied force, max deflection and slope at the free end respectively and can be determined by Eqs. (1)-(3).

$$\delta_{max} = \frac{Pl^3}{3EI} \tag{1}$$

$$\theta = \frac{Pl^2}{2EI} \tag{2}$$

$$y = \frac{Px^2}{6EI}(3l - x) \tag{3}$$

3. The assembly clearance analysis

3.1 Simulation background

The support has two important clearances Δ1 and Δ2 with different parts as shown in Fig. 2. The effect of these clearances on arm assembly performance is investigated through FEA simulations of assembly structure in different process scenarios. Practically, Δ1 might be present due to tendency of a very minute gap (≤ 1 mm) at the mating surfaces of support and housing caused by misalignment or any other reason for not mating properly. It is investigated in the increments of 0.25 mm. On the other hand, Δ2 is inevitable for successful assembly of Support and Arm. It is the difference between support internal and arm external diameters at their mating position.

FEA simulations are used effectively for structural analysis of parts and assemblies in different commercial CAE softwares. In assembly structural analysis, different application conditions can be applied to an assembly structure in order to investigate its performance. On the other hand, CAD-CAE integrated environment helps in modeling different geometry instances and application conditions efficiently. In this research, modeling different clearance values need minor variation in geometry resulting several digital geometry instances, the same is very expensive to carry out physically. Moreover, varying process conditions are required to be applied so that the assembly performance can be checked thoroughly at different process scenarios. Therefore, the digital simulations are considered replacement for physical prototyping and testing unless applied wrongly. In this research, FEA based assembly structural analysis is relied to yield appropriate results for the application.

3.2 The result

The simulations results for Δ1 are shown in Fig. 4. The results show that in clearance range of Δ1 = 0 to 1 mm, the effect on different stresses is negligible. The values are close to each other for each applied force case. The anticipated reason for such results is that Δ1 values in that practical range do not alter the loading and resistance conditions of arm assembly to a great extent.

The simulation results for Δ2 are shown in Fig. 5 which shows that with the increase in Δ2 there is remarkable increase in σB1. For lower forces, the stress values are almost same for different Δ2 values. The lowest stress values are for $\Delta 2 = 0$ (i.e. no clearance), but it is not feasible practically unless the Support and Arm is a single part. In order to realize assembly of support and arm, there has to be some clearance between two diameters. However, the minimum possible suited value satisfying the acceptable amount of stresses and δ_{max} induced can be opted yielding ease of assembly and better performance. The reason for min σB1 at no clearance is that in such a situation, there is always a surface contact between support and arm, therefore, inducing an effective role of support right from the beginning of applying force. As a result, it provides max resistance to the applied force and cause min stress and δ_{max}. σB also shows nearly the similar trend as σB1 whereas σBH values don't vary remarkably with Δ2. Similarly, the impact of Δ2 on deformation (δ_{max}) can also be observed from Fig. 5 which enhances with the increase in Δ2. Therefore, it is another limiting factor while selection of clearance value.

From the above-presented results, it can be deduced that Δ2 helps in absorbing some impact of applied force, and this absorption reduces stresses to some areas in assembly. For a particular application scenario, both these opposite effects need to

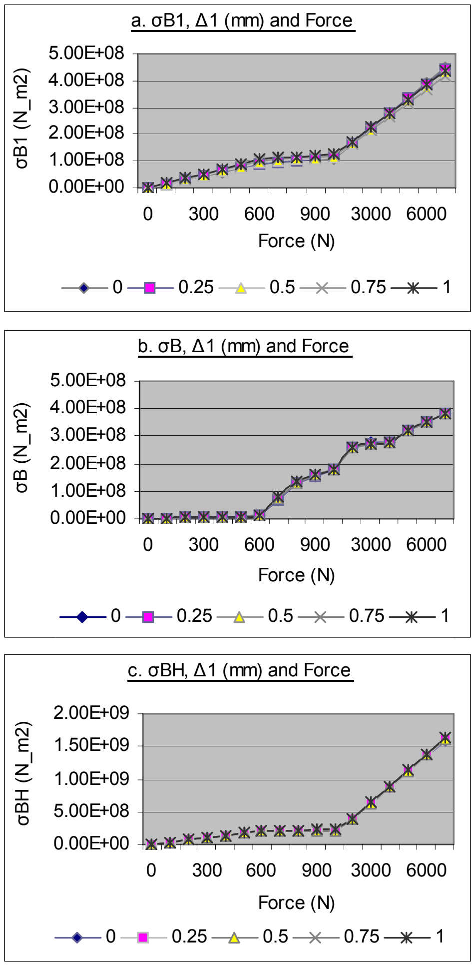

Fig. 4. Effect of Δ1 on different stresses at different applied force values.

be analyzed for successful design. In short, it can be deduced that assembly clearances such as Δ2 affect product functional parameters such as different stresses and displacement. Clearance analysis can provide guidance for defining values of these clearances keeping in view assembly's practical conditions.

4. Conclusions

Following conclusions can be drawn from the research presented in above-mentioned sections:

There are certain assembly clearances which are not part of tolerance stack but still they can affect overall assembly functionality and product performance. Therefore, the relationship of such clearances with product functional parameters can be determined and used for a better design.

The function analysis of different clearances (Δ1 and Δ2) shows that Δ1 contributes nothing significant to the product functional parameters; however, the impact of Δ2 is remarkable. Appropriate Δ2 values can be selected based on these results while satisfying other considerations. The mating parts final dimensions and tolerances can be based on the best suit-

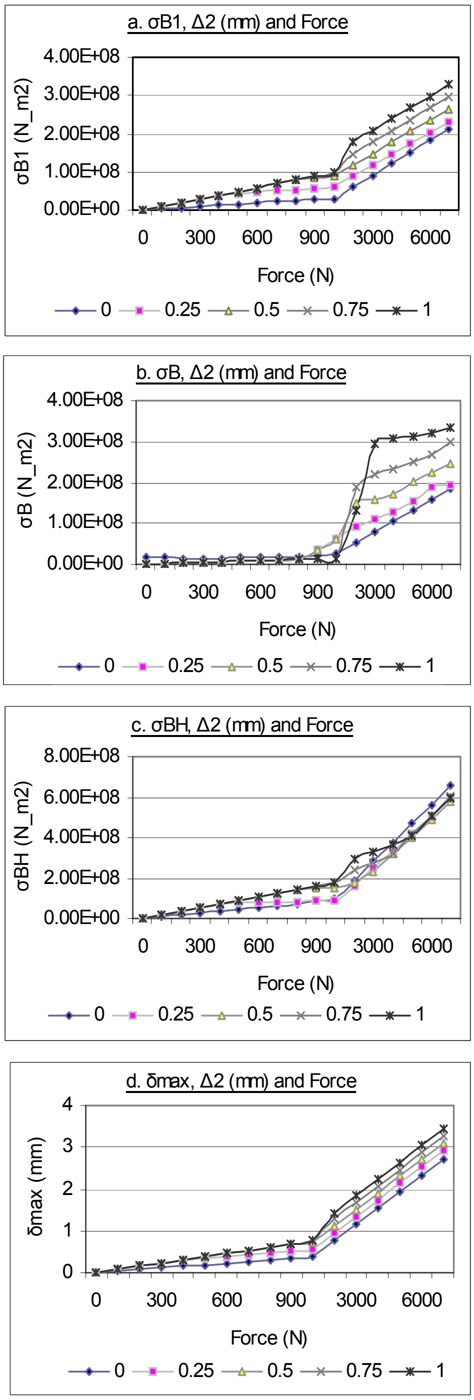

Fig. 5. Effect of Δ2 on different stresses and δ_{max} at various applied force scenarios.

able Δ2 value selected.

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Ahmad Zia is a Ph.D candidate at Beihang University in Beijing, China. He received BSc mechanical engineering degree from University of Engineering & Technology, Taxila, Pakistan and MSc degree in advanced manufacturing technology and systems management from the University of Manchester, UK. He has several years' industrial experience in the field of advanced manufacturing, process planning and control, maintenance of machines & equipment, and production management. His research interests include CAD/CAM/CAE, design geometry optimization and product development engineering.

Lihong Qiao is a professor and chairperson of the Department of Industrial and Manufacturing Systems Engineering at BeiHang University (BUAA), China. She received her Master and Ph.D Degree in mechanical engineering and automation in BUAA. She started teaching in BUAA in 1986. She has been a guest researcher in the National Institute of Standards and Technology (NIST). Her research interests include product development engineering, product lifecycle management, digital manufacturing and information integration. She has published over 100 journal and conference papers. She is committee members of Production Engineering Branch and Group Technology Branch of the Chinese Mechanical Engineering Society.