

# Finite Element Modeling and Experimental Study of the Spline Tube Forming

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*Received: August 19, 2015; Accepted: October 8, 2015*

## Abstract

Metal forming processes, compared with machining ones, reduce production steps and increase manufacturing speed in addition to saving raw material. In this paper, forming process of column of a steering mechanism is investigated by finite element analyses and experimental tests; and optimum die design parameters are found. Forming process parameters including die opening angle, bearing length, clearance between work piece, die and friction coefficient were studied. Some new ideas were also used in manufacturing process of dies with compression tube forming process. Without using an appropriate lubricant, friction coefficient between die, tube, the probability of tube distortion and tube bulging increased significantly. The forming force is also strictly dependent on friction coefficient and it also increases with increasing bearing length of the die. The manufactured sample had good agreement with the original drawing of profile appearance and dimensions. Effects of die and tube clearance on the required force and final part surface quality are also investigated.

## Keywords

Steering column, Finite element analyses, Cold extrusion

## 1. Introduction

Steering system is one of the most consequential automobile systems in driver's safety and comfort. Steering system components are categorized into safety and ultra-safety parts. Each steering system includes the steering wheel, steering column and steering box. In some cars, sliding intermediate shaft is located between steering column and steering box. This part's function is the transmission of torque without backlash and vibrations without chattering between steering column and box. Among other functions, telescopic steering can minimize the damage to the passenger caused by car accidents via absorbing steering column impact, changing the height of the steering wheel relative to the driver. In trucks, changing telescopic steering length has the additional benefit of moving passenger cabin up and down. The clearance between tube and shaft of the intermediate shaft should be less than 0.5 degree after the assembly operation.

Considering that forming process of the tube and shaft of the intermediate shaft have not been done in Iran before, and these parts are imported from countries such as Japan, this study was designed to localize production in our country. Figure 1 shows steering column assembly with two universal joints at both ends.



Figure1. Steering column assembly

Material removal techniques have been used in manufacturing of many parts in automotive industry in the past decades. In recent years, automotive world industry has changed track to use forming technologies, rather than material removal processes in their productions. The main advantages of the forming processes are high accuracy combined with high productivity. The cold forming of spline tube has greater potential than cutting, because of its many outstanding advantages such as saving raw materials, high productivity, superior product quality and low cost [1].

This change of track from material removal processes to forming processes results in energy consumption reduction and decrease in environmental pollution. Cold tube forming is used to obtain closer dimensional tolerances and better surface [2]. The main advantages of cold extrusion as opposed to hot extrusion are that good mechanical properties imparted to the work piece due to the severe cold working, good surface finish with the use of proper lubricants and no oxidation of the work piece. Cold metal forming process allows the use of lower strength metals without subsequent hardening operations on work piece. In other words, work hardening of parts increases by applying this process [3, 4].

The die opening angle and bearing length have been studied in different articles and books to obtain die design properties. American Society for Metals reported die opening angle for hollow parts from 60 to 120 degree [5]. ASM also reported die opening angle for this material from 40 to 140 degree [4].

Mapani et al. [6] used bridge dies for hollow tube forming. In his studies, the optimum bearing length was considered as main die design parameters. They also reported die and mandrel profile as other main parameters. He explored a variety of die and mandrels shapes and reported that optimum die length is has been the major factor in extrusion die design. Die and mandrel profiles are other deciding factors in selection of hollow die for extruding tubes. He also reported that if the shape of die and mandrel be the same, the average load and energy consumption in process will be the lowest average figures. He explored that by increasing bearing length, friction force also increases.

Fujikawa et al. [7] from Nissan Company studied hot and cold forging technique in some vehicles. He introduced die opening angle as one of the main parameters of metal forming process. In his studies, the bulging problem in die entrance was reported.

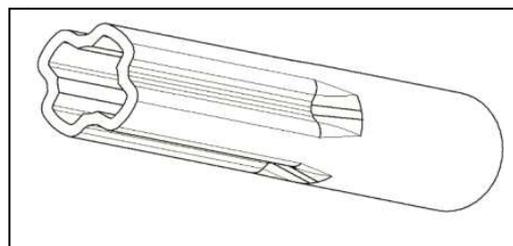


Figure2. Schematic view of formed tube

Huang et al. [1] achieved a model for solving bulging problems of the tube end in extrusion process. He also studied bearing length and die opening angle with experimental tests. His solution is based on adding a guiding length at the die entrance to restrain the expansion of the bulging, so that the extrusion accomplishes successfully.

The term “distortion” in this study refers to the axial displacement deviation that exists in the extruded product, relative to a straight transverse line perpendicular to the centerline of the extrusion in the final product.

Amborn et al. [8], from GKN auto part manufacturing company, studied manufacturing technology of hollow tubes for manufacturing side shaft of vehicles. He also evaluated different methods for manufacturing this part.

Naseri [9] reported force analyses of cold extrusion. He made a comparison between theoretical, FE and experimental methods. In this research, it was simulated extrusion process in abaqus software and finally achieved a good compliance between three methods.

Gordon et al. [10] has investigated distortion during extrusion of products. They determined a die shape that would allow an extruded product to be produced with minimum distortion. Ebrahimi et al. [11] used numerical and analytical solutions for obtaining die semi angle. Hu et al. [12] used ring compression test to determine friction coefficient in cold forging of parts.

Reviews of the previous works reveals that comprehensive method to optimize die parameters of spline tube shapes has not been presented yet. Therefore, the present study proposes a comprehensive method for designing preform dies using compressive tube forming. In this project, after studying various forming methods, accuracy and ease of making one, forming in cold extrusion (compression) was selected for manufacturing this part.

## 2. Methods and Materials

### 2.1 Elastic-Plastic Properties of materials

In this research, precise carbon steel seamless tubes (1.1141) were used as tube raw material. Table 1 shows the result of chemical analysis of the tube.

Table 1.chemical composition of selected tube

Composition	C	Mn	Si	S	P
	%	%	%	%	%
	0.176	0.551	0.236	0.002	0.017

Tensile test was conducted to obtain the elastic-plastic properties of the tube according to ASTM-E8. The sample prepared for tensile test is shown in Figure 3. Elastic-Plastic behavior of the material is also shown in Figure 4.



Figure3. The sample prepared for ring compression test

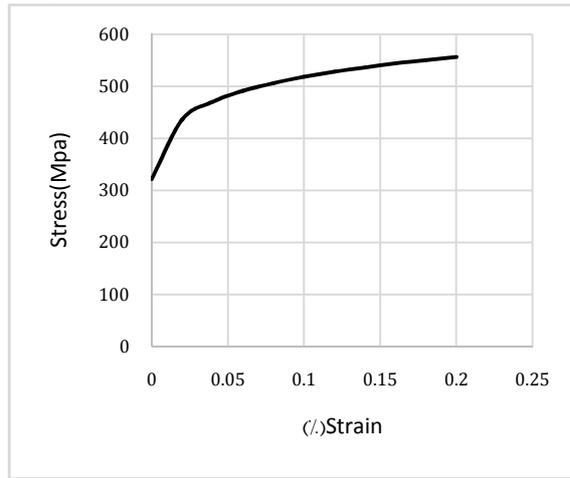


Figure4. Elastic plastic stress-strain curve [13]

2.2 FE analyses of cold compression forming

FE analysis based on ABAQUS Explicit was used to determine die design parameters. Optimization of die opening angle and bearing length was carried out. Furthermore, effect of friction coefficient between the components and effect of clearance between die components were examined. Figure 7 shows die opening angle and bearing length. For the simulation process, all the parts including die, mandrel and tube were modeled in Autodesk Inventor.

All of the parts were imported in abaqus. The explicit method was used to perform the simulation. Three dimensional simulations were carried out in Abaqus 6.11 assuming that the work piece (tube) is deformable. Due to the complexity of die and mandrel, it was not technically possible to consider the parts analytically rigid in Abaqus. For this reason, die and mandrel are considered as “discrete rigid” and shell. Coulomb friction model with friction coefficient of 0.1 was used in simulations. This value was obtained based on the ring compression test results. Figure 8 shows assembled parts in Abaqus.

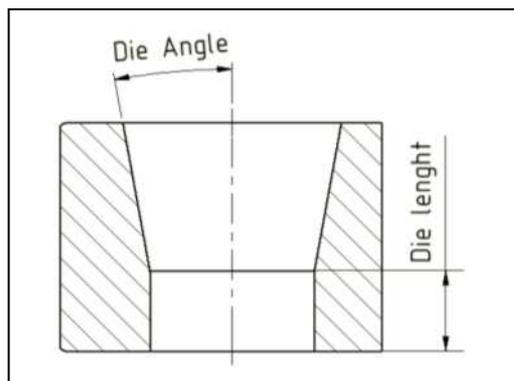


Figure7. Section view of die opening semi angle of 7.5°

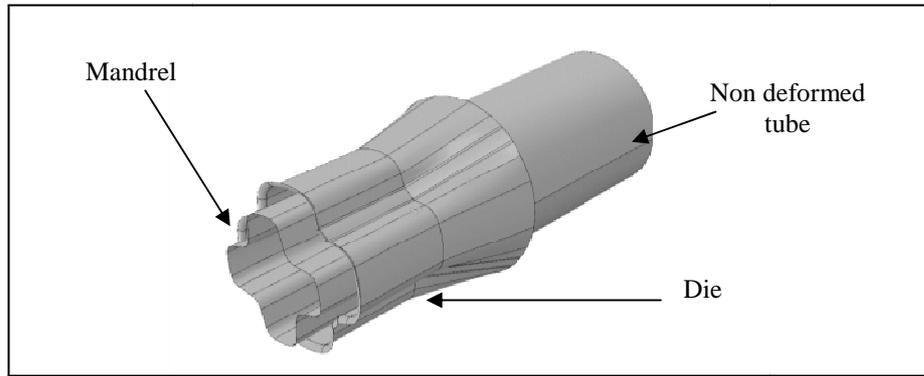


Figure8. Tube, mandrel and die in abaqus assemble module

As seen in Figure 8, die and mandrel are fixed in all directions. Die is considered as linear hexahedral element of type C3D8R with reduced integration while mandrel and die are linear quadrilateral elements of type R3D4. Figure 9 shows the meshed parts.

In this study, FE forming analyses fall into three major groups. The first group is based on modeling the forming without the presence of mandrel. In the remaining two groups, forming the tube with different values of die opening angle is investigated.

### 2.3 Forming tube without mandrel

First, the mandrel was removed from the model to investigate the effect of presence of the mandrel on the forming system. As shown in Figure 10, the tube corners have not been formed completely and are far different from final profile.

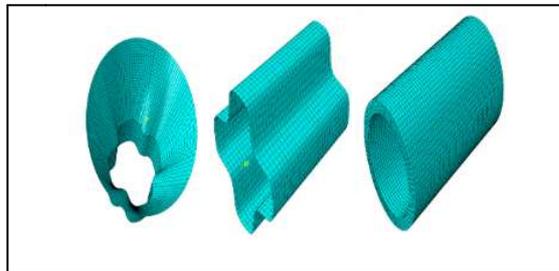


Figure9. Tube, mandrel and die that are meshed in abaqus (right to left)

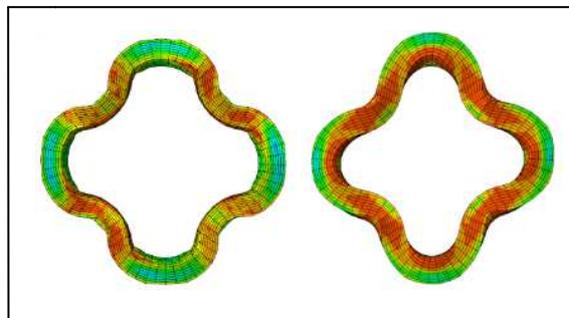


Figure10. Formed tube without mandrel on 15° angle (right side), with tube and mandrel (left side)

*2.4 Investigation of different die opening angles (with mandrel)*

Second groups of analyses were performed on die opening semi angle from 20 to 60 degree. In the third groups of analyses, the die semi angle varies from 7.5 to 15 degree.

In the second groups of angles, die opening semi angle was investigated in 20,25,30,40, 50, 60 degrees angle. In these die opening angles, tube distortion and tube bulging occurred during the forming process.

Reducing die opening angle resulted in decreasing the tube distortion problem. As shown in figure 11, 12, tube distortion in  $2\alpha = 60$  degree is more than  $2\alpha = 40$ .

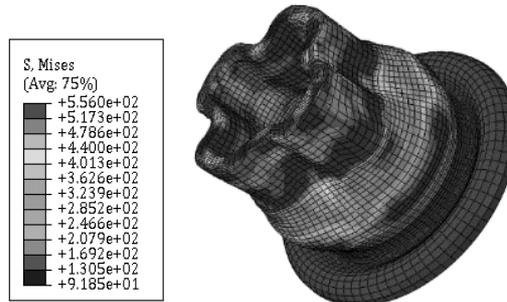


Figure11. Formed tube on 30° semi angle

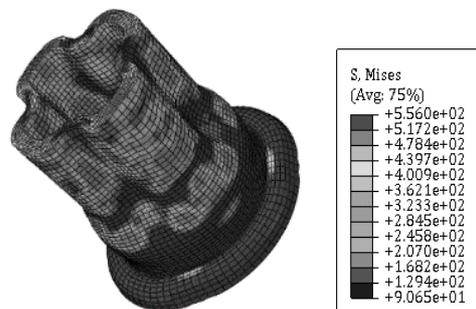


Figure12. Formed tube on 20° semi angle

In these simulations, bearing length was reduced to 20% of its initial size. Consequently, the distortion was reduced.

In order to optimize the die opening angle, for forming the telescopic shaft, the quality of tube surface, dimensions and forming force was compared in all products. Simulation results of the first groups of angles show that the tube undergoes distortion in all angles and the process ends inconclusively. The effect of different values of friction coefficients on tube forming was also examined. The friction coefficient of 0.1 was considered for FE analyses (according to the value obtained from practical test). To evaluate the variations of the coefficient of friction on the tube forming behavior, analyses with coefficient of 0.01(similar to frictionless) and 0.05 were carried out. As it can be seen in Figure 13 and 14, with a lower coefficient of friction, distortion in the tube end has been reduced.

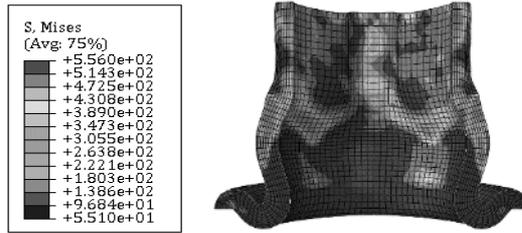


Figure13. Formed tube in 25 degree semi angle and 0.1 friction coefficient

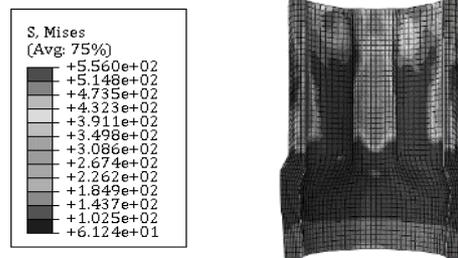


Figure14. Formed tube in 25 degree semi angle and 0.05 coefficient of friction

Third group of angles was simulated similar to the previous analysis, except that the die opening angle was reduced to 15, 20, 25 degree. Figure 15 illustrates formed tube in 25 degree.

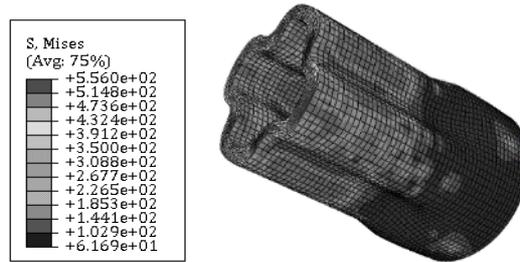


Figure15. Formed tube on 25 degree

The effect of friction coefficient variations on the loading force in this angle has been investigated, as shown in Figure 16.

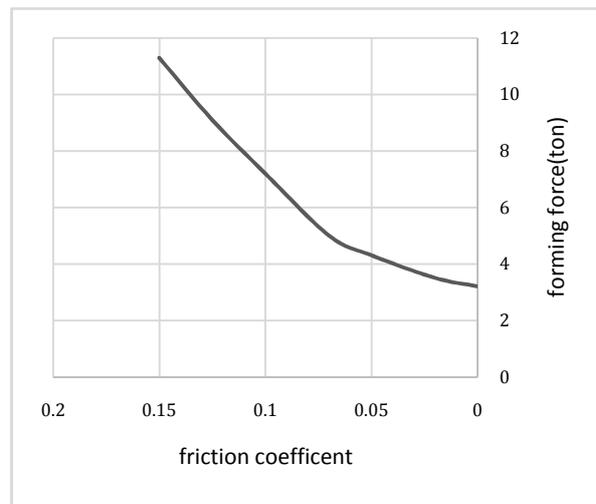


Figure16. Relation between friction coefficients and forming force on 15°

The clearance between die/tube and mandrel/tube has been compared with forming force in Figure 17. Forming force increases in order to increase decreasing clearance.

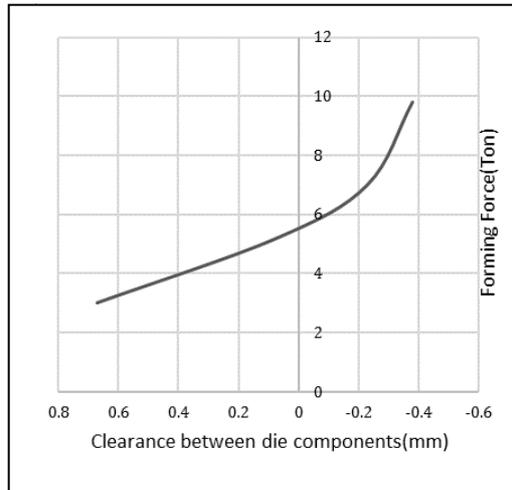


Figure17. Relationship between tube diameter and forming force

### 3. Manufacturing of the forming system components

A view of the die design template is shown in Figure 18. The die has two surfaces; the inclined surface that guides the tube into the die and the bearing length that finally sizes the outer surface of the tube. Figure 7 shows the die and the bearing length of it.

During the forming operation, maintaining the concentricity between the die, mandrel, tube and alignment of the parts is very important.



Figure18. Manufactured forming system

### 4. Experimental test

Different test conditions had performed for comparing FE results with experimental tests. Tube used in experimental test is a seamless cold drawn tube. Annealing process was used to improve tube mechanical properties. Mandrel was not assembled on system in the first test to investigate the effect of existence of mandrel on forming system.

The reaction force was measured in all of the testes. A calibrated pressure gauge is installed on the forming system to measure system pressure performance and calculate reaction force on tube, as shown in Figure 19.



Figure19. Pressure gauge installed on system

In the second tests, the tube manufacturing properties have been investigated. Besides that, the role of the clearance between the die, tube and the mandrel besides the tube forming force has been studied. In this test, 0.2 mm interference was set between the tube, mandrel and the die. In this test, forming process was successfully completed. However, a little amount of distortion and bulging remains in the tube. In the next test, the clearance between the die components was set to 0.1 mm which led to better outside surface quality of the tube. The results showed that there is a good agreement between profile and surface roughness of formed tube with the original drawing of the tube. In the fourth test, 0.7mm clearance was set between the components. (See table2 for more details)

## 5. Discussion

The Manufactured forming systems have multiple advantages over other methods; it could manufacture products with minimum operational time and it could manufacture high precision products while the products can be manufactured with less operator intervention. By using innovative mechanism, precision direction adjustment of die and mandrel became possible in the forming system. The die opening angle was changed from 7.5 to 60 degree in order to investigate forming quality and precise of tube in FE analyses. These angles were categorized into two groups, group B and group C. Group B was comprised of the angles in range of 25° to 60° and group C included the angles between 7.5° to 20° degree. Bulging occurred in angles of group B thus the forming process could not be completed. The results showed that the bulging problem was stemmed thus formed tube quality improved in group C angles.

Based on the results of group C, the 15° die opening angle was selected for manufacturing experimental sample of the die. The advantage of 15° die opening angle over the other angle options is its ability to optimize the forming force and deliver good profile quality. Furthermore, the effect of friction coefficient variations on the loading force in this angle has been investigated, as shown in figure 16. With increasing friction coefficient, the loading reaction force increased proportionally.

After analyzing different results, the 15° of angle had been chosen for manufacturing experimental forming system, due to the better product's quality, more precise dimension and less forming force. The results showed the necessity of existence of the mandrel in forming system. Mandrel helps to guide the material flow to the edges of the die and the mandrel. Figure 22 shows the manufactured

tube with and without mandrel. Figure 23 shows the resulted profile from FE analyses compared with experimental test samples without the mandrel. Figure 24 shows the comparison with the presence of the mandrel in the system. Results show that in 25° die angle, the tube distortion decreased, but the distortion completely disappeared in 20° and 15° angle and at the same time a very good agreement with the original drawing shape was reached.

FE results show that reducing friction coefficient from 0.1 to 0.01 reduces forming force about 50 percent. This shows the role of lubricants in forming process. The bulging also decreased following forming force reduction. Increasing average forces applied on tube is the result of increasing bearing length of the die. Reducing bearing length in the samples mitigated the bulging problem considerably. The results imply that if clearance between the tube, the die and the mandrel is about 0.1mm, distortion and bulging will not be observed in the formed tubes, and forming force is in the allowable range; furthermore, tube surface roughness value is acceptable.

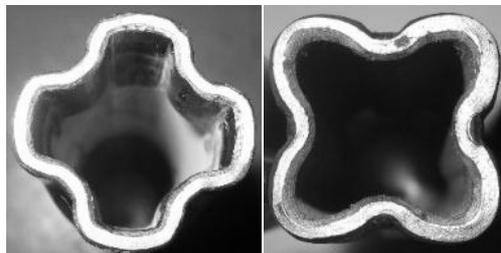


Figure22. Formed tube without mandrel (right) and with mandrel (left)

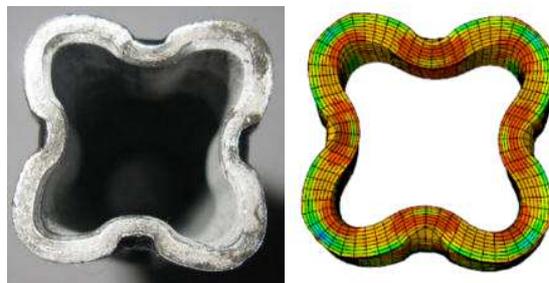


Figure23. Formed product from experimental testes (right) and FE (left) without mandrel

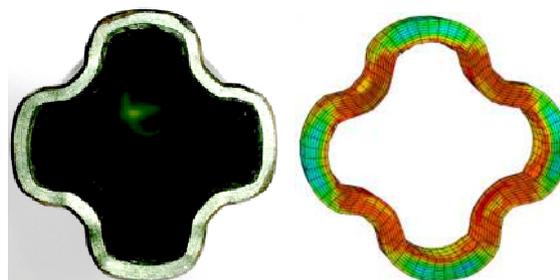


Figure24. Manufactured tube and FE analyses tube with existence of the mandrel

Table 2 shows dimensional comparison between theoretical and experimental formed tube. The results show that average forming force in a typical tube in the experimental test is 30% higher than that of the theoretical results. For instance, when the clearance between the die, tube and mandrel is about 0.1mm, forming force is 7 tons in the experimental test, and forming force in FE result is 5.5

ton. Figure 25 shows forming tube from experimental test with 0.1mm clearance resulted in a perfect specimen that satisfied all of the expected requirements.



Figure25. Formed tube with outside diameter of 27.85 and 0.1 mm clearance

Some variations may exist due to the increasing friction coefficient in experimental test. Increasing friction coefficient to 1.25 could increase forming force up to 30%. In addition, error in measurement of friction coefficient or the effect of pressure on lubricant performance could affect the forming force.

Table2. Results from theoretical and experimental tests

forming force	Inside product diameter	Outside product diameter	Clearance between parts	Die diameter	Mandrel diameter	Theoretical and experimental results	
10	22.8	28	-0.2	27.93	22.98	Experimental	1
7.5	22.82	27.9		27.90		theoretical	
7	23.04	28	+0.1	27.93	22.98	Experimental	2
5.5	23	27.94		27.90		theoretical	
4.5	23.1	27.5	+0.7	27.93	22.98	Experimental	3
3.5	23.3	27.78		27.90		theoretical	

## 6. Conclusion and Results

In this paper, a special kind of hollow tube compression forming with finite element method and experimental test had been investigated. As a result, the final specimen with required quality and precision was manufactured. Appropriate die opening angle for forming this tube was less than 20° angle and optimum angle was 15°.

Forming force is an important criterion in forming process, due to the costs associated with it, including the price of equipment, power consumption, etc. Friction coefficient has a large effect on forming force. Bearing length affects distortion and bulging of tubes and forming force. For achieving the desired precise profile of the tube, utilization of a mandrel is crucial and clearance between mandrel, die and tube should be within the proper limits.

## 7. Acknowledgments

The authors would like to appreciate the R&D director of Farman Khodro Sepahan (FKS) Company for their financial support of this study.

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