CHAPTER 1

INTRODUCTION

1.1 Introduction

Tube Hydroforming is one of the most important technologies in the modern industry allowing for the production of light and high strength parts such as: aircraft structures, car bodies and other structural parts, utensils or household equipment. It allows for obtaining good quality products in a very short time which is very important because of the high competition in the manufacturing market.

1.2 Classification of Tube hydroforming process based on sensitivity to loading parameters

1.2.1 Pressure driven

THF processes that do not need feeding (a small bulging ratio) or can be fed very little (a part with too many bindings, protrusions, etc. along the tube) fall into this category (engine cradle may be one example). Then the two loading parameters are reduced almost to one. Since there is no or little feeding, there is basically little risk of wrinkling in this group. However, the risk of leaking could be high, especially in the case of zero feeding, due to relatively large axial tensile stress.

1.2.2 Pressure dominant

Parts in this group have an expansion ratio larger than those in the first group, so more axial feeding is essential for the successful bulging of the parts. Once large feeding is involved, there will be a new risk of wrinkling or buckling. On the other hand, due to the nature of a relatively large expansion ratio, the deformation may exceed the pressure instability point. Starting from this point, a drastic expansion sets in without increase in the internal pressure, hence the risk of fracture increases.

1.2.3 Feeding driven

The medium that is commonly used in THF is water. The compressibility of water is relatively low, with a bulk modulus of about 2.2 GPa, which means that a 2% decrease in volume will generate a pressure of 44 MPa which is a relatively high pressure for bulging of the Y-shape. Hence, less feeding is required as compared with the internal pressure of water.

1.2.4 Feeding dominant

This process involves parts with characteristics of a relatively small locally bulged area and little self-feeding phenomenon. This does not mean that feeding is not important. For some parts, the amount of feeding could be very large compared with the bulged area and is essential to the successful forming of the part. Typical examples are T-shape and X-shape conjunctions.

The general principle of tube hydroforming is displayed in Figure 1.1.

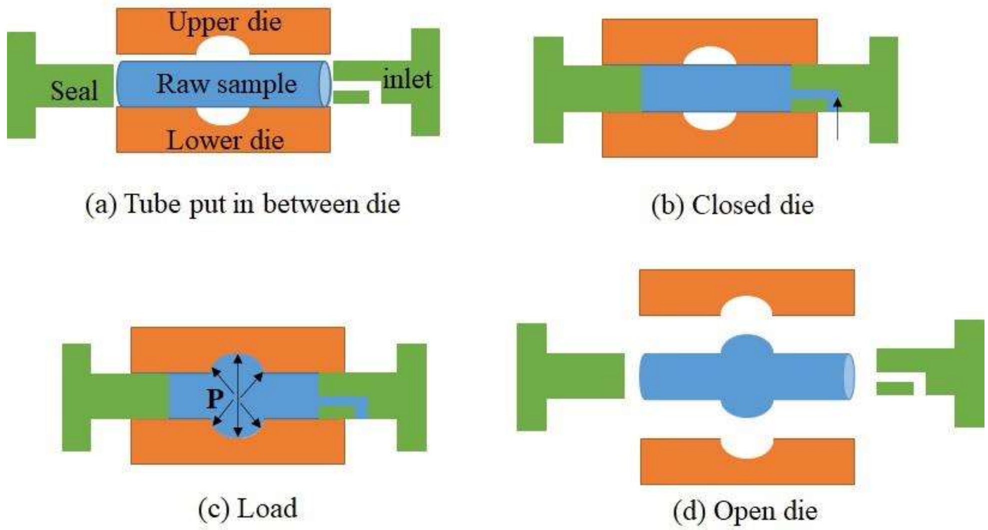

Figure 1.1: General tube hydroforming System Layout [14]

The tubular blank is firstly placed between the two die halves and then filled with high-pressure liquid through holes in the plungers. The tube blank is then forced to adopt the inner contour of the tool by the application of internal pressure (via high pressure liquid) and two axial forces (via plungers) simultaneously. For limited applications, the tube can be formed by the increasing internal pressure only. This means that the axial plungers do not feed more material into the expansion zone. However, the axial forces acting on the tube ends must exceed a certain level to prevent pressure liquid leakage. This limit is known as sealing.

In many cases, internal pressure can be transmitted by means of an elastomer (e.g. rubber or polyurethane). A polyurethane rod was acting as the pressure-transmitting medium in Al- Qureshi [4]. The same author replaced polyurethane with rubber to provide internal pressure [4]. In another study, tubular components were formed by pouring soft tal (filler material) into a copper tube [5] and then applying end axial forces to both the filler material and copper tube.

1.3 The main components of tube hydroforming systems

1.3.1 Hydraulic Powerpack Systems (Press)

Figure 1.1.1: Hydraulic Powerpack Systems [10]

In contrast to other forming operations, in THF process, presses are used to open and close the die and to provide enough clamping load during forming period to prevent elastic deflections and die separation. Necessary tonnage of the press (or clamping device) is dependent on the required closing force. It is, in turn, a function of the maximum internal pressure takes place during forming, part size (i.e. diameter, length and thickness), and material. Large components with thick walls (i.e. chassis components) and intricate regions (i.e. small corner radii) need high closing forces up to 7000-8000 Tonnes. At present, presses up to 10 000 Tonnes capacity are in operation at several plants in the world. Existing hydraulic presses with appropriate closing forces and bed sizes can be utilized for THF process [with some necessary additions and changes in the system. Clamping devices, other than regular hydraulic press systems as shown in figure 1.1.1, are being designed and tested for hydroforming purposes. The purpose of developing special clamping devices is to increase capabilities on process control, obtain better dimensional accuracy via high clamping load, access larger bed size, reduce cycle time, increase flexibility for different parts and reduce investments, etc. In such a design, the ram with the upper die half is actuated up and down through a small cylinder, which would provide rapid motion and cost less. As the ram closes the dies at its bottom position, two opposite and horizontally positioned cylinders are actuated to lock the ram at its required location. Moreover, several other small and short-stroke cylinders at the bottom of the press bed are moved up to further increase the clamping load capability. Such a design would not only be cost effective in terms of initial capital investment, but also would provide rapid stroking, which consequently contribute reducing the production cost. In principle, a THF press or machine must have the following features:

i) appropriate die closing force;

ii) appropriate bed size to hold the dies;

iii) adjustable/movable axial punches with computer controlled positioning;

iv) adjustable/movable rams for counter forces with free and position control;

v) optional: automatic work-piece handling;

vi) high pressure (2000-5000 bar) and fluid pumping capability with tight control.[6]

1.3.2 Die and Tooling

Hydroforming tooling consists of die holders, dies, inserts, punches, sealing systems and sometimes counter punches or movable inserts. Figure 1.1.2 shows the assembly of Die/Tooling system. Due to the high-pressure values involved in THF process, strong tooling systems are required to minimize die deflection and part tolerance deviations.

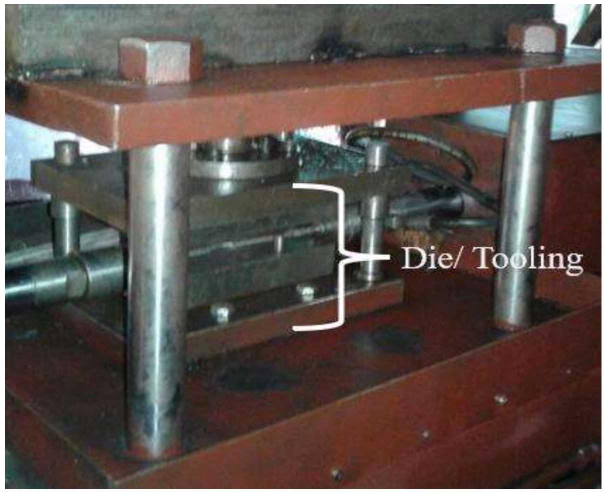

Figure 1.1.2: Die/Tooling attachment system [8]

Hence, tool steel such as D2 is used for inserts, whereas die steel material is used for the dies. Inserts are usually hardened and polished to achieve smooth surface finish to reduce friction and die wear. Design of part positioning and parting lines requires full attention since through which not only necessary closing force can be reduced but also formability of the part can be guaranteed. For structural parts, diagonal positioning is one way of balancing the die deflection between vertical and horizontal directions of the part. Because of confidentiality issues in this high demanding technology, limited information regarding tooling design is released to the public as it goes with other aspects of the technology. Hence, common guidelines known for forging and stamping technologies are applied in combination after necessary improvements and trials.

In general, the followings are main requirements for THF tooling [7,8-10]:

(1) high strength against stresses due to large internal pressure and axial loading;
(2) good surface finish to minimize friction and increase formability; flexibility by interchangeable inserts;
(3) good guiding systems;
(4) balanced design to minimize the closing force requirements.

1.3.3 Pressure system

The pressure system (pump, intensifier and control valves) should be designed and selected, so as to provide the required pressure levels for a wide range of parts to obtain flexibility in the system invested. Figure 1.1.3 shows the Pressure system of Tube Hydroforming Process.

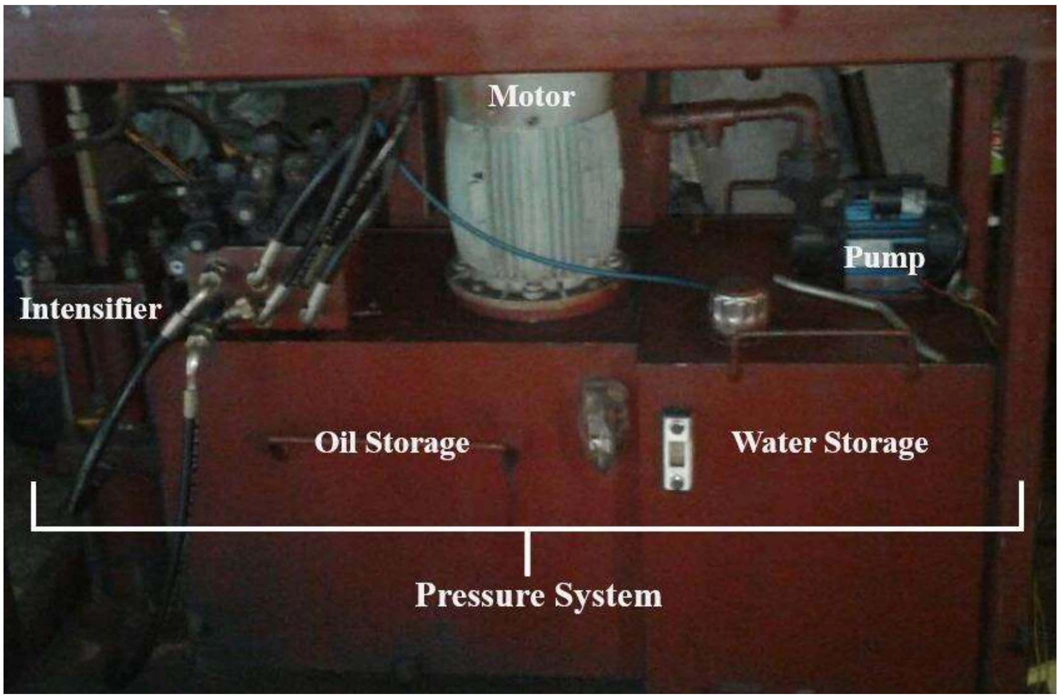

Figure 1.1.3: Pressure System [11]

The applied pressure should have a range from 20 MPa (30 ksi) up to 100 MPa (150 ksi) depending on the parts in consideration [11]. In many current industrial applications using pressures up to 300 MPa (450 ksi) are sufficient. The flow rate can reach up to 50 l/min in order to allow short cycle times. In order to increase the production rate, multiple intensifiers are used to shorten the pressurizing period and compensate time losses in case of rapid pressure increases when required by any part and process design.

1.3.4 Axial hydraulic cylinders and plungers

The axial cylinders are necessary to: (a) seal the end of the tube to avoid pressure losses and (b) feed material into expansion regions. They should feed the material into the deformation zone in a controlled way, and in synchronization with internal pressure, i.e. pressure versus time and axial force versus time should be controlled and coordinated. Counter punches are sometimes used on bulged or protrusion sections to avoid premature fracture by providing a controlled material flow. Axial cylinders are expected to generate forces of up to 7000 kN (700 t) while counter cylinder limits extend up to 2000 kN (200 t). The smaller size also allows close control of the punch position. Various punch tip designs for effective sealing during hydroforming have been developed. Figure 1.1.4 are the Axial hydraulic cylinders and plunger arrangement of tube hydroforming process.

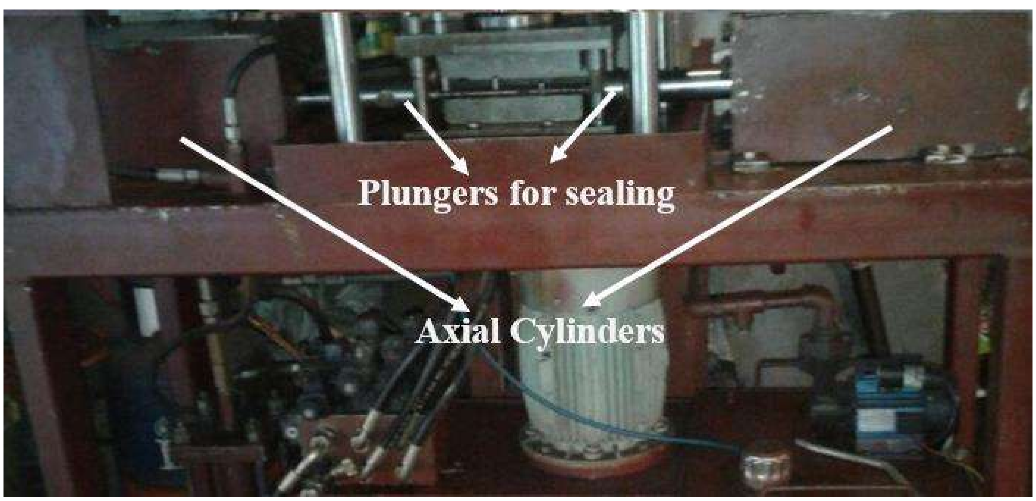

Figure 1.1.4: Axial hydraulic cylinders and plungers [10]

Tube hydroforming offers several advantages as compared to conventional manufacturing methods. Tube hydroforming offers the following advantages:

1. Better part quality (tighter tolerances, part consolidation, weight reduction through more efficient section design, improved structural strength and stiffness, and good surface finish).

2. Lower manufacturing costs resulting from a reduced number of forming and assembly operations, lower tooling cost due to fewer parts, fewer secondary operations (no welding of sections required, and holes may be pierced during hydroforming) and less waste.

The main application of this method has been found in manufacturing of reflectors and household appliances, as well as components in the hygiene, aerospace, automotive, and aircraft industries. Many companies in the automotive sector are experiencing great success with this process as it reduces weight, overall costs, and the number of parts per vehicle [12]. Automotive applications can be seen in exhaust parts, camshafts, radiator frames, front and rear axles, engine cradles, crankshafts, seat frames, body parts, and space frame. Tube hydroforming is also used for the manufacturing of bathroom faucet spouts, aluminium riflescopes, and steel panic bars. [13-16]

1.4 Motivation and research objective

In spite of the important applications of the tube hydroforming, a knowledge base study does not exist for elliptical specimen as the process for the square, spherical, X, Y and T shape tube hydroforming. Consequently, a detailed investigation on the elliptical tube hydroforming process is required to help engineers to attain better understanding of the process and allow a detailed explanation of the effects of the design parameters on the elliptically hydroformed part. Particularly, bulge height, and uniform wall thickness without wrinkling, corner radius is the goal of most manufacturers.

The main objective of this study can be summarized in the following points:

(a) Numerical modelling of the Aluminum 6061 T4 alloy elliptical tube hydroforming process using the finite element method to help engineers to gain greater efficiency in the process development, avoiding the cost and limitations of compiling a database of real world parts.

(b) Mechanical behavior of the Aluminum 6061 T4 alloy samples before and after hydroforming.

(c) Experiments to check the numerical model validation.

(d) Employment of the Design of Experiments technique and Finite Element Method to model the Elliptical tube hydroforming process outputs as functions of the geometrical factors (die corner radius, tube thicknesses of elliptical bulge out layers) and the internal pressure process parameter. By means of these models, a quick estimation of the process output can be obtained. Furthermore, the main effects and their interactions on the process outputs can be graphically displayed.

1.5 Thesis layout

In the first chapter, a general introduction on the tube hydroforming process is outlined and the importance of the tubing and its application is highlighted. This chapter also presents the research motivation and the objective of the current work. The second chapter presents a literature review on tube hydroforming studies in which the factors affecting the process output are addressed. Chapter three describes the complete tube hydroforming set-up design layout including procedure follow for components fabrication and finally assembly of the tube hydroforming machine components. The experimental procedures using the tube hydroforming machine are also mentioned in this chapter. In the fourth chapter, numerical models are created for elliptical bulge Al 6061 T4 alloy tube hydroforming samples on various geometrical factors such as thickness variation, corner radius and bulge height with process parameter such as different internal pressure range. Chapter five presents a comparison of the design parameters (geometrical factors and process parameter) on the elliptical bulge tube hydroforming process output using a combination of Experimental technique and finite element models. Chapter six outlines the conclusions of this study and makes recommendations for future work.