Sheet-Metal Forming Processes with Local Plastic Deformation by using Conventional Spinning Methods - Introduction

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Abstract: In the present paper is carried out a literature review of the scientific works and publications concerning the processing of sheet-metal by local plastic deformation using the method of conventional spinning. The idea to write the article arose after a thorough search for technical literature and information on the subject in Bulgaria and it was found that such information is insufficient or incomplete. It is necessary to review and systematize knowledge about spinning from Antiquity to the present day, which will serve as a basis for future research in the field of local plastic deformation achieved by the method of spinning.

Keywords: flow forming, spinning, deformation of sheet material, deep drawing

I. INTRODUCTION

This review presents a survey of most literature published on spinning methods in English language. This paper aims to provide insight into mechanics of the process and act as a guide for factory technologists, craftsmen, designers, structural, product designers researchers working on conventional spinning and other flexible forming processes. Some elements of the theory, technology, devices, machines and tools for deforming hollow axisymmetric parts by applying a localized deformation load are reviewed [1,2].

Spinning is a technological process for the production of axisymmetric parts in the form of hollow volumetric bodies with an opening on one side made of sheet metal up to 25 mm wall thickness. As a result of the localized deforming force on the sheet blank, the initial material assumes the shape of a model and an axisymmetric part is obtained. Its application could be in the engineering, agricultural, lighting, furniture, food, medical, architectural, military, space, aircraft, telecommunication, textile, transportation and other industries. Multi-staged conventional spinning is the preferred technology for molding not only thin-walled hollow bulks, but also large-sized and thick-walled products [2].

Today, the spinning technology has lost popularity in Bulgaria, while on the other hand in Germany, Japan, France, USA, China, India, etc. has reached a very high technological level. Small production workshops have also been preserved, in which hollow axisymmetric products are made by hand with not very high accuracy. In the next few pages, will be briefly described where sheet metal processing by local plastic deformation in the conventional spinning method started and where it is today.

II. HISTORICAL FACTS

Spinning is a craft that can be traced back to thousands of years and has been widely used since the dawn of civilization. It has been suggested that the process of metal spinning was inspired by the art of making clay pottery using [1]a manual-powered potter's wheel by the Pharaohs in ancient Egypt [3]. The earliest known pictorial evidence can be traced to the 4th century tombs of the early Ptolemaic Egyptian pharaoh Petosiris [3]. The earliest recorded references to spinning of metal date back to Antiquity, when the ancient Egyptians used primitive hand-powered lathes to spin metals such as silver and gold. There is also evidence that similar lathes were used in Ancient China, highlighting the importance of metal-shaping and metalworking capabilities to early civilizations.

The helmets of Roman combat units were made by methods today known as drift/ manual spinning (Fig.1). Such desired shape was obtained from a disc-shaped piece of metal turned on a wooden or metal mold. A large force was needed to perform this, probably obtained by means of a water wheel. This invention appeared during the so-called Dack wars (101 – 106 CE) during the reign of Trajan [4].

As the art of spinning grew significantly, spun metal parts like teakettles and trophies were first produced in the Middle Ages (Fig.2) [3]. At the beginning of the 20th century, spinning was considered an art rather than science, as it required operators with considerable experience and skill.

Fig.1 Roman cavalry helmet from the 1st century CE Object found in Witcham Gravel, Ely, Cambridgeshire (England) [4]

Fig. 2 Wooden spinning lathe with a manually operated flywheel to spin the workpiece [3]

In 1945, the first hydraulic lathes were introduced to form

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thicker and stronger materials. With the aid of hydraulic power, the operator could operate the roller through the hand-operated valves.

Later in the mid-20th century, thicker sheets were required to be spun to make components of higher dimensional accuracy. This led to the emergence and automation of spinning machines. One of the driving forces behind this development was from the aircraft and aerospace industries in countries like the UK, USA, Germany and Sweden [3]. Typical components produced by mechanically powered spinning machines are components for gas turbine engine, rocket nose cones and antennas' radio wave reflectors. Due to hydraulic power and automation the flow forming technique has evolved, to meet further demands of original equipment manufacturing (OEM) industries [5].

In the early 1970s, the increased demand for faster production rate and improved quality led to the development of CNC (Computer Numerically Controlled) spinning machines [6]. This system offers greater flexibility as tool trajectories can be programmed and complicated parts can be formed of materials previously considered difficult to work. Compared to the hydraulic pattern-spinning machine, CNC machines expanded the range of component configurations that can be formed. However, the downsides of CNC systems were the high cost and the need for experienced spinning operators with programming skills.

Under such circumstances, the 1980's saw the development of a teaching system, known as programmable numerical control (PNC). With the aid of playback control, the spinner teaches the machine what it has to do in a subsequent spinning operation. Programming is not by means of numerical data but by outlining a path with the spinning roller under manual control. Thus, the skilled operator is in a position to apply all his experience to the corresponding forming process [6].

Conventional spinning is defined as a process in which the diameter of the workpiece is intentionally reduced either along the entire length or in specific areas, without any change in wall thickness. Conventional spinning is done in only one stage. However, in cases where metal of large gauge or high strength is rotationally drawn, unilateral loading is exerted, which is undesirable. In such cases, two rollers placed diametrically above each other should be used. Rotational molding provides manufacturers with an alternative to conventional forging and deep drawing where the size or complexity of a component's shape is beyond the capacity of conventional presses [7].

Today, spinning can be applied to many automotive products. The ability to enable the metal to flow along complex paths using simple tooling not only eliminates the sequence of transitions in deep drawing presses, thereby reducing costs, but also offers the potential to produce lightweight mandrel with a simple shape [8].

III. Spinning machines

A. The Spinning Lathe

The principal tool used in the operation of spinning is the spinning lathe, shown in Fig. 3 and Fig. 3.1 [9]. While in many respects this machine is similar to any other lathe, it is built without back-gears, carriage or lead-screw, is very rigid in construction, and, as a whole, very much resembles a speed lathe. Like other lathes, the spinning lathe is fitted with a cone pulley (preferably of wood, because of its lightweight and gripping qualities), allowing the use of four or five different speeds. Speed is an important factor in spinning. Arbitrary rules for spinning speeds cannot be given, for thicker blank the speed must be slower; thus while $^{1}/_{32}$-inch iron can be readily spun at 600 rpm, $^{1}/_{16}$-inch iron would necessitate reducing the speed to 400 rpm. Zinc spins best at from 1000 to 1400 rpm; copper works well at 800 to 1000; brass and aluminum require practically the same speed, from 800 to 1200; while the comparatively slow speed of 300 to 600 rpm is effective on iron and soft steel. Britannia and silver spin best at speeds from 800 to 1000 rpm [2,8,9].

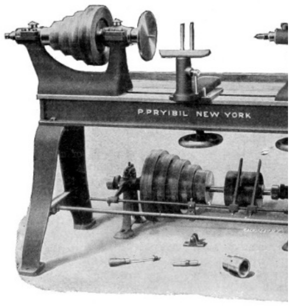

Fig.3a Spinning Lathe 1912 New York [9]

Fig.3b Layfield DB 20 Spinning Lathe 1956, 225-2800rpm [9]

Figure 4 shows the development of this technology and some of the equipment needed for the process. The presser (1) presses the workpiece (2) against the mandrel (3) and thus the spindle (4) transmits spinning motion through the mandrel to the workpiece. Through the support pin (5) a lever effect with long arm is obtained through which we easily apply force to make the detail.

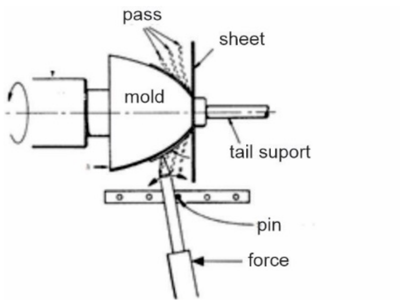

Fig. 4 Conventional manual spinning [3]

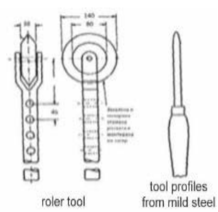

Fig. 5 Manual spinning tools

The workpiece can be deformed by a movable tool - a roller (Fig. 5 left) or a solid tool (Fig. 5 right). The advantage of a hard tool is that it can deform hard-to-reach places such as small rounds and edges, but the disadvantage is that we have very high friction, which leads to faster tool wear and need for greater applied force.

B. Hydraulic Spinning Machines

The first hydraulic spinning machine in the world is introduced in 1945. Hydraulic spinning machines for large workpieces were developed after 1960 (Fig.6). With clamping of the mold at the flange according to DIN (German Institute of Standardization) Standard 55022, mold diameters over 1100 mm, spindle rotates from 2 to 300 rpm at a motor power of 53 kW/h. Workpiece pressing force is 14000 kg, and pulling force of 25000 kg (Fig.7), with longitudinal feed from

0.005 to 3.2 m/min., and transverse feed from 0.000 to 1.5 m/min.

Fig. 6 The hydraulic spinning machines for large workpieces

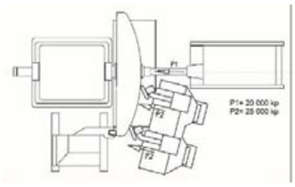

Fig.7 Pressing force of the workpiece *P1*, pulling force *P2*

C. Machines with Digital Program Control (DPC)

After the third industrial revolution, were created lathes with digital program control adapted for spinning. In fig. 8 shows a diagram of the operation of such machines. In terms of movements, it is the same as that with manual control, with the addition of a stop behind the workpiece, which makes the workpiece more stable and prevents curling, which is a consequence of tangential stresses. In most cases, the longitudinal and transverse feed is carried out by means of hydraulics. The hydraulics compensate for inaccuracies in the mandrel and thus we get excellent results. Creating programs in the conventional way for these machines is laborious. Because of this recently they are equipped with a joystick that copies the coordinates through which the operator passed during the download. With these lathes, we can add permanent oil mist lubrication where we can vary the ratio of air to oil. Pulling such lathes requires quite precise tools. Radial and axial runout should not exceed 0.05 mm, otherwise there will be large deviation in the product and greater wear of the tooling.

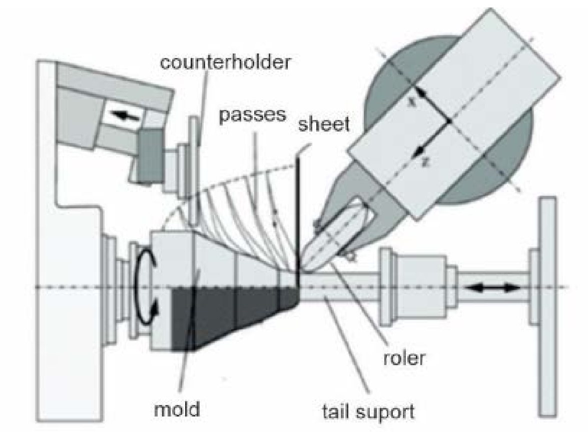

Fig. 8 Schematic illustration of the conventional sheet metal spinning process [10]

D. Programmable CNC Lathe with Playback

The playback spinning machine from NIHON SPINDLE [11] has been performing successfully in the market since 1989. More than 400 machines are in daily operation worldwide. The Model T500c is equipped with a four-post turret for tool change on the carriage as standard. Four different tools can be mounted on the turret for faster operation. These tools will be spinning rollers, corner shaping rollers, trimming tools, curling rollers, etc.

The reliable performance and functionality of the machine gives metal spinners the confidence to spin consistent quality every day.

Fig. 9 The spinning machine with reproduction from NIHON SPINDLE [12]

Fig.10 The spinning machine with reproduction Model T500 [13]

III. Methods of Processing Blanks Depending on the Change in the Wall Thickness of the Workpiece

A. Spinning

1) Spinning is a forming process in which a planar blank or a hollow rotating body takes the shape of the profile of the product pattern with the help of the moving deforming force. A characteristic feature of the process is the localized deformation area obtained as a result of the action of the deforming tool (the deforming roll).

2) An advantage of spinning due to strain localization is that it enables high strain rates (up to 80%) to be obtained in one pass. This makes it more cost-effective than other deformation methods.

3) There are three primary processes within Metal Spinning. Each method is characterized on its deformation of materials, the relative position of the surface roller and the blank, spinning with or without a mandrel, and finally, the temperature of the blank.

B. Conventional spinning

Conventional spinning (also known as compression forming) (Fig. 8) is one of the principal working methods to produce thin-walled rotary shell workpieces, because it has many evident advantages over forming processes, such as smaller deformation force, lesser investment in equipment, etc. The wall thickness of the finished product is equal to the thickness of the blank with which it originally started. Depending on the size, materials used and quality requirements of the part, it is possible to produce the part in one pass (stage).

In conventional spinning, the wall thickness is determined by the number of roll passes and the direction of each pass. When the roller surface moves forward, the material becomes thinner, when moved backward, the material moves in the opposite direction, which provides a constant wall thickness and reduced internal stresses. A process known as "smoothing" is used to improve the surface and accuracy of the piece. Smoothing consists of finishing passes by the warping roll, the purpose of which is to remove the waviness produced as a result of the various transitions during the process. A high radial force is applied as the feed rate decreases.

Two sub-processes of necking deformation (Fig. 11 left) and internal expansion (Fig. 11 right) can also be performed by this conventional spinning method.

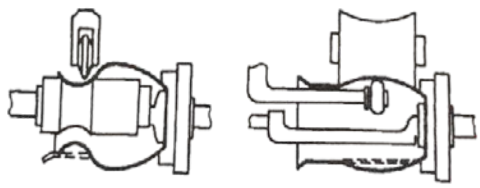

Fig. 11 Spinning with offset center and internal expansion [14]

C. Flow forming

Flow forming is the second method and it is commonly referred to as tube spinning, and is closely linked to shear forming/spinning. In flow forming process, material is forced to flow over a shaped, rotating mandrel by application of pressure through external rollers. This process is used for manufacture of large motor-casings like booster segments of rockets. There are several variants of flow forming process like Spinning, shear forming etc. This process is widely used in the production of aviation fuel tanks, because the other options for the production of aluminum tubes is the extrusion or rounding of aluminum sheet and subsequent butt welding. With extrusion, we have a limit on the outer diameter, and with the seam tube, which is obtained after welding, there is a problem with some of the materials. Most types of aluminum that are used for this purpose do not have good welding qualities and because of this, we have a limit in wall thickness. Principle of flow forming process and schematic diagram of seamless tube making through flow forming is shown in Fig. 12.

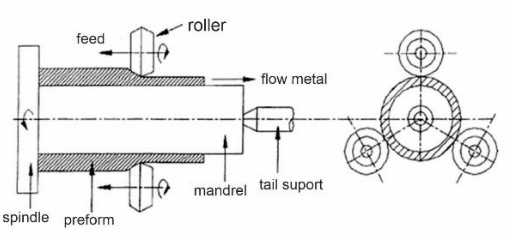

Fig.12 Schematic diagram showing principle of Flow Forming [15]

Flow forming can be considered an advanced form of metal spinning. The main difference between the two processes is that the starting material in the metal spinning process is thinner than that used for flow forming and the resulting component is produced from a larger diameter preform [7].

D. Shear Forming

1) Shear (**sliding**) spinning is the third method of Metal Spinning and forms sheet metal over a conical mandrel. This is often performed on a conventional metal spinning lathe. Parts typically made by this process include rocket-engine casings [16]. Parts up to 3 m in diameters can be spun to close dimensional tolerances. Because of the large plastic deformation involved, the process generates considerable neat, which is usually dissipated by coolant-type fluid applied during spinning.

2) The final thickness of the part, t_1, is determined from the Sine law, where α is the angle of the mandrel and t_0 the initial blank thickness. The key impact of the Sine law is that a small angle α will produce a smaller thickness t_1, requiring larger levels of deformation.

$$t_1 = t_0 * \sin\alpha \quad \textit{(Sine law)} \tag{1}$$

3) As such, the minimum angle of the mandrel possible to shear form is in the range 10 to 18°, depending on the material being formed; smaller angles as low as 3 to 4°, however, can be achieved using multiple passes. Deviations from the Sine law are sometimes observed and lead to failure or defects in the part, which are due to induced stress, a phenomenon directly noticeable on the flange of the workpiece.

4) When a ticker starting material is spun or the gap between the mandrel and the roller is too small (over-reduction) the mandrel will build up progressively ahead of the roller causing the vertical unspun flange to lean forward towards the headstock. This excessive build-up of material will result in the thickness at the roller contact to deviate from the sine law thickness, i.e., $t_1 < t_0$ *sin (∝)*. The opposite situation, with a thinner starting material or if an oversized gap is set (under-reduced), the flange is pulled inwards and it may wrinkle, again causing the ultimate thickness to deviate from the sine law, i.e., $t_1 > t_0$ *sin (∝)*. Figure 15 illustrates the consequences of over-reduction and under-reduction; this can be attributed to the defects during the process, which are going to be described further in this work.

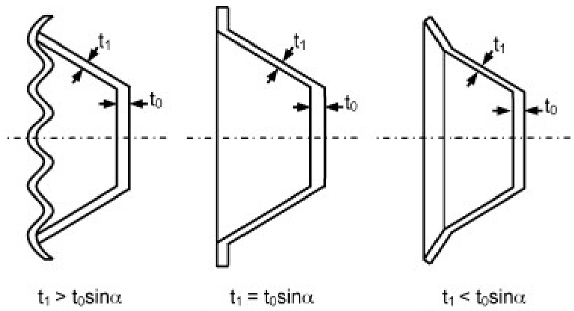

Fig. 15 Effects on the flange of deviation from Sine Law [16]

Basic knowledge and understanding of the axial, radial and tangential forces is critical. The pressure we need to apply to obtain plastic deformation for this technology is calculated with the formula [7]:

$$P_i = F_t . r . 2\pi n \tag{2}$$

Where *n* are revolutions per min., *r* is the radius of the largest section, F_t is the tangential force, which we find with the formula:

$$F_t = \frac{k_f}{\sqrt{3}} f . S_0 \cos\alpha, \tag{3}$$

where *f* is the feed mm per revolution, $k_f = \sigma$ for conical parts, S_0 is the thickness of the workpiece, and α is the cone angle.

These formulas are for a material with an elasticity, which is constant throughout its volume and do not include bending and modulus of elasticity.

Like flow forming, the wall thickness of the blank is intentionally reduced, and this is dictated by the angle at which the wall of the part and the axis of rotation are.

There are contrasting differences in this method of metal spinning, as the roller stretches the material over the mandrel in a single pass. The compressive force applied whilst the roller moves ensures the outer diameter of the finished part is equal to the original diameter of the blank.

Unlike conventional spinning, shear spinning does not produce cylindrical shapes, due to the 'shear angle' of the vertical walls at 0-deg. Hence the name, shear spinning.

V. Conclusions

This article reviews various machines for manufacture through spinning, from Antiquity to the present day. Despite different control - manual, hydraulic, CNC, they are all still used today. The main methods of spinning are described, where the degree of deformation can reach up to 80%, under certain conditions. The pressures for the realization of these deformations are not at all small and change depending on several factors at the same time. It becomes clear that spinning is a very complex process in terms of deformations and stresses in the workpiece not only in the area of application of the deformation force, but also on the remaining undeformed part of the workpiece. By complicating the shape and dimensions of the models, it inevitably leads to new stress states in the workpiece and is a challenge for defect-free manufacture, which in turn means that the potential for development in this scientific field is great, especially for the production of complex shapes that are not made yet, and are increasingly sought after by the industry.

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