METHOD OF DEEP DRAWING SHEET MATERIAL
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The invention relates to a method of forming spheroidal articles of sheet material, particularly sheet metal, by deep drawing the thin sheets metal with the help of a spherical punch having projecting forming surfaces and of means stretching the sheet material across the punch while the latter is moved transversely to the material. The term "spheroidal" includes not only true spheres but all convex surfaces of revolution in which the instantaneous peripheral line of contact between the blank and forming punch increases from an interior point of initial engagement to the outer margin of the final formed article. This is to be distinguished from flat-bottomed cupped articles in which the bottom portion is not actively involved in the drawing action and in which there is no change in the length of the instantaneous periphery of action at the outer portion of the punch.

In forming spheroidal sheet metal articles by deep drawing it is customary to hold opposite marginal regions or the entire circumferential region of a sheet metal blank and to exert a force restraining the marginal regions from moving toward the center of the punch during the forming operation.

Known procedures and equipment lead to conditions in which the blank is subjected to different stretching in different areas so that the finished article has varying thickness. Often the different stretching leads to rupturing the blank while in other regions the stretch is so small that practically no change of the original thickness of the blank is obtained.

It may help the understanding of the invention to first describe in some greater detail what occurs in conventional deep drawing where the metal blank is first positioned and held in a blank holder, and the punch then contacts the blank and starts forming it. At any given instant after the start there are three fairly distinct areas to be considered, namely: (a) a static area of metal which has been formed around the punch, (b) an active transition area where the metal is tangent to the punch, and (c) a stretching area, extending from the transition area to the blank holder, in which the metal is under tension. It is within the instantaneous spherical area, line or zone where work is being done. If the blank is held tightly and the draw is deep, the metal may be stretched to failure before sufficient load can be developed by the increasing cross-sectional area of the transition or instantaneous forming zone to cause metal to move through the blank holder. This may be further complicated by the speed-sensitive static friction factor.

The object of the invention is to provide a method of deep drawing spheroids by which all areas of the blank are subjected to virtually the same specific amount of stretching to produce a substantially constant wall thickness of the completed article over its entire area.

The object of the invention is achieved by varying the restraining forces exerted on marginal portions of the blank throughout the forming operation so that the ratio between the restraint at the instantaneous cross-sectional area of deformation to the length of this line or the size of said cross-sectional area is kept virtually constant. Instantaneous means in this connection the area or line subject to deformation at any given instant. When the instantaneous area or line of deformation increases, the restraining force will be increased correspondingly with the result that the same specific stretch is imparted to this instantaneous line or area as to a smaller line or area of deformation having correlated thereto a correspondingly smaller restraining force. Preferably the variations of the restraining force are programmed in advance by calculations and/or trial runs.

More specifically, the invention deals with the type of deep drawing in which a circumferential marginal area of the blank is held between margin holders while a punch forces or draws the central portion of the blank into an opening of the margin holders or the cavity of another die in which case the restraining force is preferably varied by varying the pressure between the margin holders.

While the primary object and advantage of the invention is to obtain an article of controlled wall thickness over its entire area, other important advantages are obtained which sometimes may even outweigh or take precedence over the primary object and advantage. It is mentioned hereinbefore that customary methods and procedures often lead to rupturing the metal due to over-stretching in one area. The novel method of the present invention avoids such over-stretching by uniformly subjecting the entire area to a controlled amount of specific stretching. This fact not only permits deeper drawing of easily deformable metals but permits drawing of relatively hard and brittle metals or alloys which were hitherto considered as unfit for forming by deep drawing. Among such alloys are for instance certain stainless steels and titanium.

Further objects, advantages and features of the invention will be disclosed in connection with or following the description of the embodiment of the invention diagrammatically illustrated in the drawings.

In the drawing:
FIG. 1 is a fragmentary vertical section, substantially along line 1—1 of FIG. 2, through a drawing press;
FIG. 2 is a fragmentary section and plan view, substantially along 2—2 of FIG. 1;
FIGS. 3 and 4 are partial replicas of FIG. 1 though showing different stages of the drawing operation; and
FIGS. 5 and 6 are diagrams of different factors influencing the drawing process shown as functions of the movement of the forming punch.

The invention is illustrated in the attached drawing and will be described in the following as applied to the deep drawing of a simple, symmetrical article, to wit a hemisphere.

The diagrammatically illustrated drawing press has a base 10 in which upright columns 11 are firmly held. Supported by and secured to the columns 11 is a lower margin holder 12. Rigidly connected with the upper ends of the column 11 is a stationary head 13. A screw 14, threaded into head 13 and provided with a hand wheel 15, carries at its lower end a movable head 16 which is guided for up and down movement on the column 11.

An upper margin holder 17 is connected with the rods 18 of pistons 19 which are movable in cylinders 20. The cylinders 20 are secured to the movable head 16 and have their tops in communication with a pressure fluid supply line 21. The provision of a plurality of cylinders 20 and their arrangement on a circle insures equal pressure distribution. Springs 22 within the cylinders 20 urge the pistons upwardly. The pressure fluid line 22 leads to a pressure control valve 23 which in turn is fed through a line 24 with an incompressible liquid.

A larger work cylinder 25 is mounted on base 10 and has a piston 26 which, by rod 27, carries a punch 28. Punch 28 fits into openings surrounded by lower and upper margin holders 12 and 17. The space of cylinder 25 above and below piston 26 communicates, respectively, with conduits 29, 30 which lead to a valve 31. The valve 31 has a slide 32 and is connected with a pressure fluid line 33, a vent line 34 and line 24 leading to valve 23.
Pressure line 33 is fed from a (not shown) source of pressure fluid. Depending on the position of slide 32, pressure fluid is admitted either to the top or the bottom of cylinder 25 so as to push piston 26 with rod 27 and punch 28 upwardly into the position shown in FIG. 1 or to retract it into the position shown in FIG. 3. In the position admitting fluid to the bottom of cylinder 25, fluid is also admitted to control valve 23 through pipe 24.

An elongated cam member 35 is connected with rod 27 and punch 28 and is movable in guides 36 provided on cylinder 25. Cam surface 37 of member 35 is engaged by a cam follower 38, the position of which governs pressure control valve 23 and thereby the pressure in conduit 21 and cylinders 20.

Punch 28 has a hemispherical working surface 39 and slidingly fits into the cylindrical opening 40 of lower margin holder 12. The cylindrical opening 41 in upper margin holder 17 has a diameter sufficiently larger than the diameter of punch 28 and opening 40 so as to provide space for the sheet material of blank 42 between punch 28 and surface 41. The upper and lower margin holders 12, 17 have plane surfaces 27 and 44, respectively, which face each other and are adapted to engage opposite surfaces of a marginal or circumferential zone of blank 42, which surrounds the central portion 46 thereof. Cylindrical surface 41 and plane surface 44 of upper margin holder 17 merge into each other by a generously rounded edge 47.

For operating the machine, movable head 16 and upper margin holder 17 are raised by screw 14 into the position indicated by dash-and-dot lines in FIG. 1. A blank 42 is placed on the lower margin holder 12, movable head 16 is lowered by means of screw 14 until the surface 44 of upper margin holder 17 engages the upper surface of marginal zone 45 of blank 42. The insertion of the blank is done while punch 28 is in its lowestmost position (FIG. 3) and pressure fluid is shut-off from control valve 23 and thereby from cylinders 20.

Admission of pressure fluid to valve 23 has the effect of energizing the cylinders 20 so that the marginal area 45 of blank 42 is firmly gripped between the surfaces 43, 44 of the upper and lower margin holders. The amount of pressure is determined by the position of cam follower 38 on cam surface 37 and by pressure control valve 23. As apparent, the pressure in the initial stage of the procedure is at its lowest.

Pressure fluid is also admitted over valve 31 (see the position of slide 32 in FIG. 3) to the lower part of cylinder 25 with the effect that punch 28 is pushed upwardly against the free central part of blank 42 and gradually deforms the blank to the shape of the working surface 39. An intermediate forming stage is shown in FIG. 4 and the final stage in FIG. 1.

After punch 28 has reached its final position (FIG. 1), it is withdrawn by admitting pressure fluid on top of piston 26, pressure fluid to control valve 23 is shut-off, and movable head 16 and upper margin holder 17 are lifted into the position shown in FIG. 1 by dash-and-dot lines.

The remaining marginal portions 45 of the finished article may be trimmed off, after removal of the article from the press, at or near the edge between them and the hemispherical portion.

So as to maintain constant wall thickness it is obviously necessary that the specific stresses $\sigma$ per unit of cross-sectional area of the instantaneous zone or line of deformation be kept at a constant value throughout the entire forming operation. This means that the specific restraining stresses $S$ (FIG. 4), effective tangentially outwardly on the work piece, have to be kept at a constant value and the total value of these stresses is to be kept directly proportional to the length $C$ of the circle of instantaneous tangential contact as shown by the upper curve in FIG. 6.

It has to be realized however that the specific re-straining stresses $S$ are not exclusively a function of the pressure $P$ exerted on the marginal portions of the blank by the blank holders though it is the variable factor employed in the embodiment for keeping the specific stresses $S$ at the desired constant value.

The main factors, other than the blank holder pressure, influencing the specific stresses $S$ at the instantaneous line of deformation, which are to be taken into account in programming the blank holder pressure $P$, will now briefly be described and discussed.

One influencing factor is the varying angle $A$ between the tangential portion 48 of blank 42 and the plane of its marginal zone 45 held between the blank holders 12, 17. The lower curve in FIG. 6 shows the angle $A$ as a function of the movement $L$ of punch 28. Angle $A$ becomes larger and larger as the forming operation progresses with the effect that the forces required for drawing the marginal blank portions 45 inwardly from between the blank holders 12, 17 grows larger and larger. Moreover, the variation of the angle $A$ leads to an increase in the width of the area of contact between blank 42 and rounded edge 47 of the upper blank holder also causing a resistance against inward movement of the marginal portions of the blank.

Another factor is that the width of the blank zone 45 held between the blank holders is comparatively great in the beginning and becomes smaller and smaller as the forming operation progresses and more and more of the original marginal zone of the blank is drawn inward.

A still further factor influencing the situation is that the marginal portions 45 of the blank have to be thickened up or pushed together as the blank is being drawn inwardly. At the start the outer circumference of the blank has a relatively large diameter whereas this diameter has to decrease more and more as the forming operation progresses. Such decrease can only be accommodated, without the formation of wrinkles, by pushing the marginal portion together. Obviously such pushing together gets harder and harder as the forming progresses because it has to overcome the initial pushing-together or flattening-up of the marginal portion.

The amount of deformation at the beginning and the change in direction between the tangential portion 48 of the blank and the gripping surfaces 43, 44 of the blank holders 12, 17 are comparatively smaller at the beginning and at the end of the forming operation. This explains the approximately horizontal initial and final end portions of the pressure curve, shown in FIG. 5 as a function of the punch travel $L$.

In spite of 46 of blank 42 and of the forming and influencing the proper pressure curve for the blank holders, its theoretical development and calculation is possible. As a practical proposition it will however often be more practical and convenient to develop the curve by test runs preceding actual production runs. For the test runs as well as for the production runs great care has to be taken to keep the surfaces of the blank holder and of the blank always in the same condition for successive drawing operation because obviously differences in surface conditions, such as rust or oil, would introduce factors which could fundamentally change the situation.

Advisely no units of length and specific pressure are given in the diagrams of FIGS. 5 and 6. It is imperative whether these units are inches or centimeters or are pounds per square inch or kilograms per square centimeter.

The general qualitative picture of the illustrated curves will be of value throughout the entire forming operation. It will be understood that, for simplicity's sake and for restricting the disclosure to easily and clearly explainable basic aspects of the invention, a press of very primitive construction has been diagrammatically illustrated. It is self-evident that for actual production screw 14 for lifting and lowering the movable head with the upper blank holder would be replaced by more conveniently operating means or that for moving the punch a
different source of pressure fluid, e.g. a compressible fluid, might be used than the incompressible fluid preferably used for the blank holder pressure.

It will also be realized that the conditions will grow more complicated if the article to be deformed is not of symmetrical simple shape such as the illustrated hemisphere and that for irregular shapes the pressures of the margin holders and thereby the restraining forces opposing the inward movement of the blank, will have to be different from each other in different circumferential zones apart from the variations of pressure to be imparted during the progress of the drawing operation.

It may be added that hemispheres of a metal, known to be very difficult to draw, have actually been manufactured to an accuracy of plus/minus one-thousandth of an inch in wall thickness variation. Hitherto the manufacture of such parts with such closely controlled wall thickness was considered an impossibility and is still considered as such by the experts in the art, who are not acquainted with the invention. The so produced hemispheres had a diameter of 6" and were formed from a blank of 11/4" diameter and .025" gauge. The initial pressure applied to the blank holders was 450 lbs. per square inch and grew to over about 1050 lbs. per square inch. Increasing the blank holder pressure may cause tearing the metal right at the start while too strong a decrease in the pressure will lead to wrinkles of the marginal portions. It was found that the radius of edge 47 has an influence on the pressure to be used between the blank holders. The production was carried out with approximately constant speed of punch travel; changes in the speed and interruptions were found to influence the result.

The invention is, of course, not restricted to the illustrated and described embodiment and its details but is susceptible to modifications and adaptations which will easily occur to those skilled in the art.

What is claimed is:

1. The method of draw-die forming a hemispherical sheet metal article having a uniform wall thickness without rupture throughout its entire surface area, which comprises, clamping a flat sheet metal blank around its outer peripheral edges, starting at the middle point and forcing the blank sheet material transversely intermittently of its clamped peripheral edges by a hemispherical-ended die punch, and increasing the edge restraining force proportionately to the increase in the length of tangential contact at the instantaneous line of engagement between the die punch and blank, and finally trimming off the edges of the blank which were clamped and not brought to the same thickness as the draw-formed hemispherical portion.

2. The method of draw-die forming a spheroidal sheet metal article having a uniform wall thickness without rupture throughout its entire surface area, which comprises, clamping a flat sheet metal blank around its outer peripheral edges, starting at a point interiorly and forcing the blank sheet material transversely intermittently of its clamped peripheral edges by a spheroidal die punch, and increasing the edge restraining force proportionately to the increase in the length of tangential contact at the instantaneous line of engagement between the die punch and blank.

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