УДК 621.983.7:539.3

PROCESS FEATURES OF STRETCH-WRAP FORMING OF THIN SHEET PARTS WITH SLOPING DOME USING THE SHEET-STRETCH PRESS

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Key words: Stretch-wrap forming**,** sheet-stretch press, corrugations.

The main problem, which often arises when you form thin sheet parts with gently sloping dome using the sheet-stretch press, is corrugations, which are hard to be removed and sometimes even impossible to be removed (see fig.1).
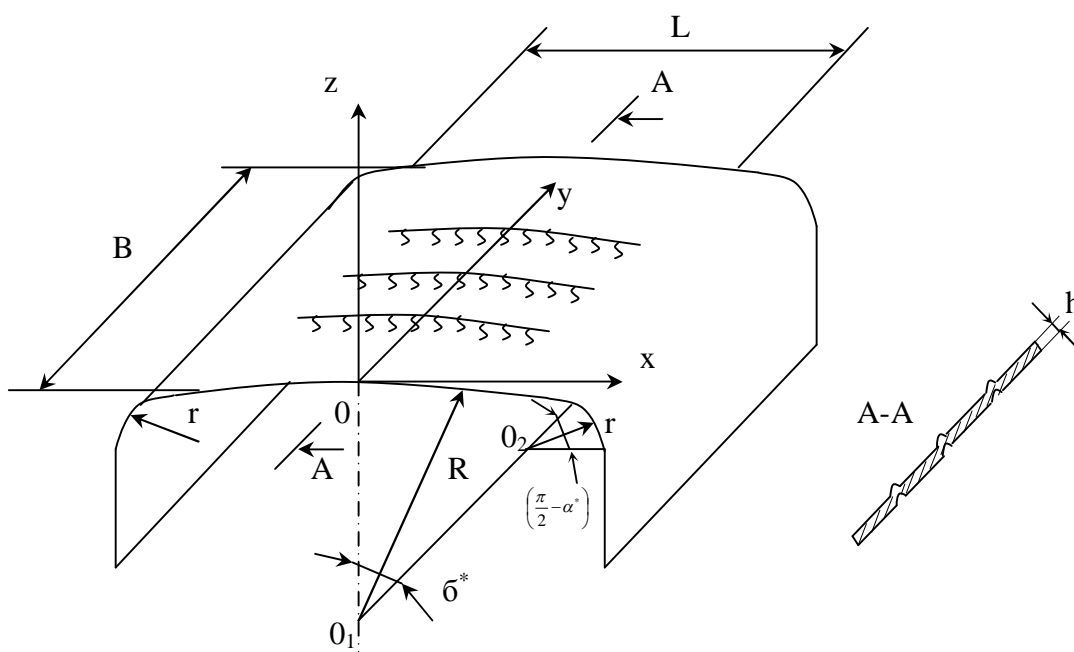

Fig. 1 Geometric parameters of sheet part with gently sloping dome (R>>r)

Lateral contraction of sheet preform, which is the cause of corrugations, is explained by the fact that it gets sharply narrow in the area where it comes off the sheet-stretch ram along the fillets with radius r at angles of capture $\alpha^* \leq \alpha \leq \left(\dfrac{\pi}{2} - \alpha^*\right)$. The dome of the preform is significantly less narrow, this results in generation of tangential stresses at the junctions of zones. These stresses provides for condition of consistency for lateral deformations ε_y. Corrugation in the dome zone can start at elastic stage of stretch-wrap forming process and continue during plastic forming, therefore the task of computation of critical stresses, which cause the loss of stability, is not just a problem of plastic stage, but can be considered at elastic stage and this is much more simple.

The lateral deformation ε_y is related to longitudinal deformation ε_x by a linear proportion

$$\varepsilon_y = -\mu \varepsilon_x, \tag{1}$$

where μ - Poisson's ratio ($\mu \approx 0,35$ – in elastic zone of deformations; $\mu \approx 0,5$ – in plastic zone of deformations).

The longitudinal deformation ε_x is determined by stretching force N, the value of which depends on friction between the preform and sheet-stretch ram. Using the well known proportion[*], let's write down:

$$N = N' \cdot e^{f\alpha}, \tag{2}$$

where e – base of Naperian logarithms;

f – friction coefficient;

α – angle of capture, which characterizes the position of sheet preform section under consideration

N' – stretching force in the central part of the preform (when $\alpha=0$).

So, for elastic status

$$\varepsilon_x = \frac{N}{EBh} = \varepsilon_x' \cdot e^{f\alpha}, \tag{3}$$

and for plastic status

$$\varepsilon_x = \left(\frac{N}{KBh}\right)^{\frac{1}{n}} = \varepsilon_x' \cdot e^{\frac{f\alpha}{n}}, \tag{4}$$

where E – modulus of elasticity;

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[*] Gorbunov M.N. Process of blank forming operations in aircraft manufacture. - M.: Mashinostroyenie, 1981 (see. formula (9.2) on page 144).

K,n – modulus and index of hardening curve ($\sigma_x = K\varepsilon_x^n$);

ε_x' – deformation in central part of the preform (when α=0).

By substituting (3) or (4) in (1) let's find out the relation between lateral deformations in random and central parts of sheet preform.

For elastic status

$$\frac{\varepsilon_y}{\varepsilon_y'} = e^{f\alpha},\qquad(5)$$

For plastic status

$$\frac{\varepsilon_y}{\varepsilon_y'} = e^{\frac{f\alpha}{n}},\qquad(6)$$

Graphs showing $\dfrac{\varepsilon_y}{\varepsilon_y'}$ versus angle of capture α for Д16М material (n=0,25), deformed in elastic and plastic status with friction coefficient being $f = 0,1$ and 0,2 are given in Fig. 2.
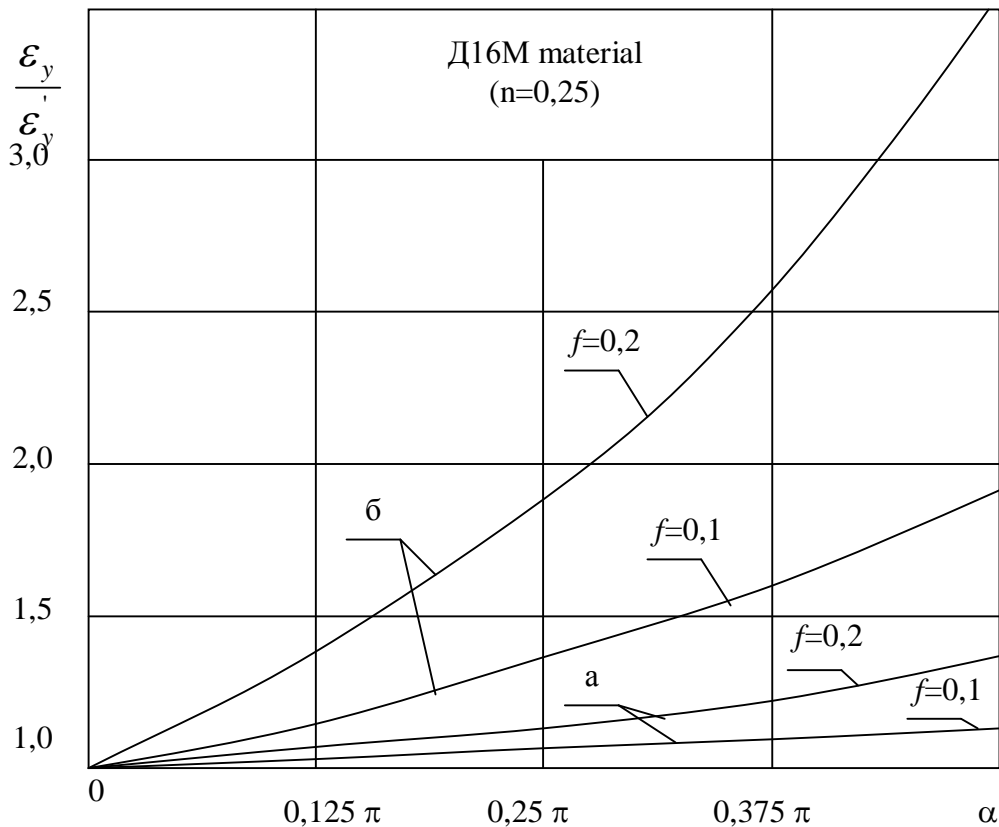

Fig.2.   Graph showing $\dfrac{\varepsilon_y}{\varepsilon_y'}$ versus angle of capture α with friction coefficient of $f = 0,1$ and 0,2; а- elastic status, б- plastic status.

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The dome part of sheet preform has the angles of capture $0 \leq \alpha \leq \alpha^{*}$. As with gently sloping dome $\alpha^{*} << \dfrac{\pi}{2}$, we can consider that $\varepsilon_x \approx \varepsilon_x'$; $\varepsilon_y \approx \varepsilon_y' = -\mu\varepsilon_x'$ all over the dome, and the width of sheet preform is constant and can be calculated using the formula

$$B_K = B(1 + \varepsilon_y) = B(1 - \mu\varepsilon_x'). \tag{7}$$

where B – is datum width of sheet preform.

The width of overhangs can be calculated using the formula

$$B_C = B\left(1 - \mu\varepsilon_x' e^{\frac{f\pi}{2n}}\right). \tag{8}$$

Fig. 3 conventionally shows on plane the dome and the overhang of the sheet preform separated from the dome. The analysis of this schematic proves that the continuity of width of
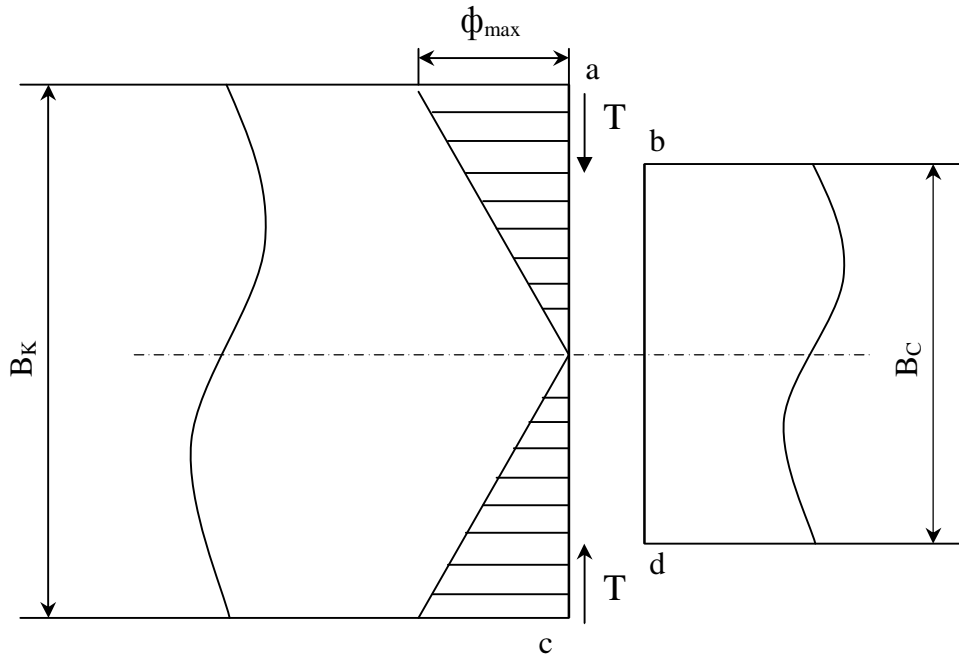

Fig. 3. Schematic of tangential stresses generation at sheet preform dome-to-overhang joint

the sheet preform can be ensured by tangential stresses, which will "compress" the size B_K and move the point «a» to point «b», as well as the point «c» to point «d». According to St. Venant's principle for self-balanced force system the attenuation should occur at a distance commensurable with the area at which this force system acts. Let's consider this distance equal to $\dfrac{B_K}{4}$, so the maximum shear deformation can be calculated using the formula

$$\gamma_{max} = \frac{(B_K - B_C)/2}{B_K / 4}. \tag{9}$$

Due to the symmetry of the sheet preform the tangential stresses are equal to zero at symmetry axis, while they reach maximum at side edges (see fig. 3). As a first approximation let's consider that the tangential stresses distribution diagram is linear. So, we can calculate the tangential forces of contrction of the half of sheet preform dome using the formula

$$T = \frac{1}{2}\left(\tau_{max} \cdot \frac{B_K}{2}\right), \tag{10}$$

where $\tau_{max} = G\gamma_{max}$ – at elastic deformations;

$\tau_{max} = K_\tau \gamma_{max}^n$ – at plastic deformations;

G – shear modulus ($G = \dfrac{E}{2(1+\mu)}$);

$K_\tau \approx 0,65\,K$ - shear hardening modulus[*].

If you imagine sheet preform dome as a part of cylindrical envelope (fig. 4), the critical contraction stresses σ_y, which cause the loss of stability, can be calculated using well known formula[**]

$$\sigma_y^{\kappa p} = \frac{Eh}{R\sqrt{3(1-\mu^2)}}. \tag{11}$$

Assuming that contraction forces T cause contraction stresses σ_y which are constant all along the sheet part dome, we can calculate the latter using the formula

$$\sigma_y = \frac{2T}{Lh}. \tag{12}$$

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[*] Relation $K_\tau = 0,65K$ is recommended in monograph: Lysov M.I. Theory and calculations of parts bending manufacturing process - M.: Mashinistroyenie, 1966 (see formula (1.70) on page 53)
[**] Iskritsky D.E. Structural mechanics of machine elements .- Л.: Sudostroyenie, 1970 (see formula (IV.17) on page 140)
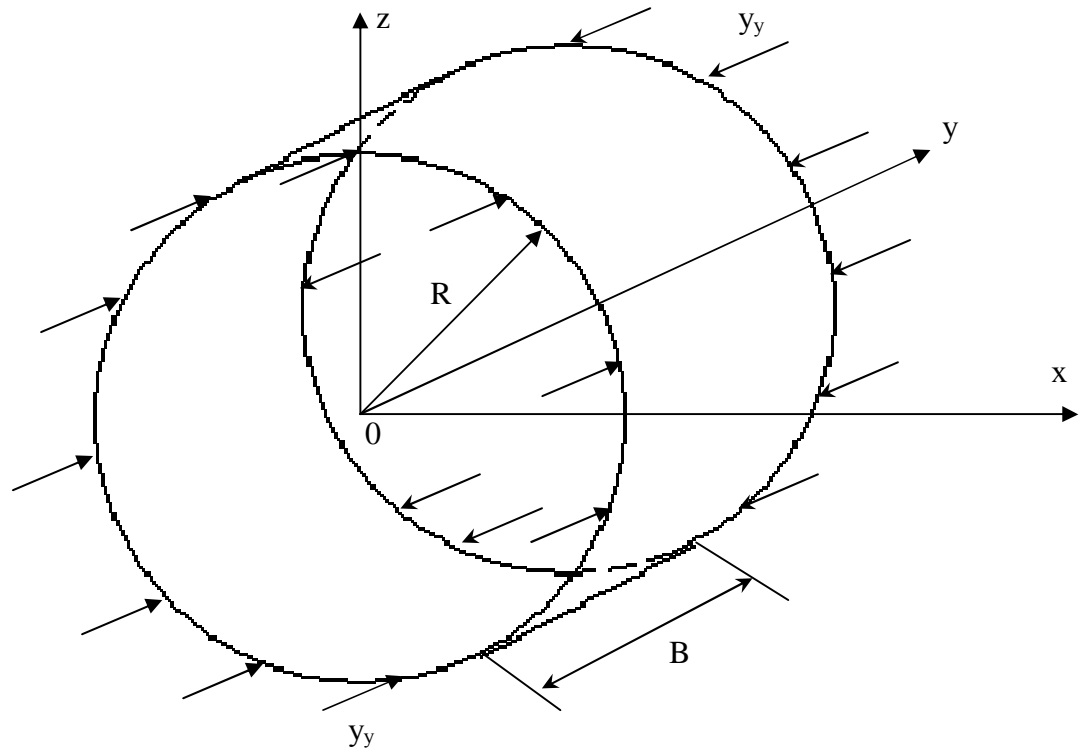
Fig. 4. Simulation model used to find out critical contraction stresses σ_y, causing corrugations

If the condition $\sigma_y < \sigma_y^{\kappa p}$ is respected, there is no danger to loss stability. Otherwise special measures should be taken to prevent possibility of corrugation.

The use of the press equipped with lateral stretchers* can be recommended as one of variant to solve the problem of corrugations. The schematic diagram of the proposed technology is shown in Fig. 5.

Along the sheet preform edges there are three lateral holders (on each side), which perform lateral stretching. Minimum values for lateral stretching forces can be calculated using the formula

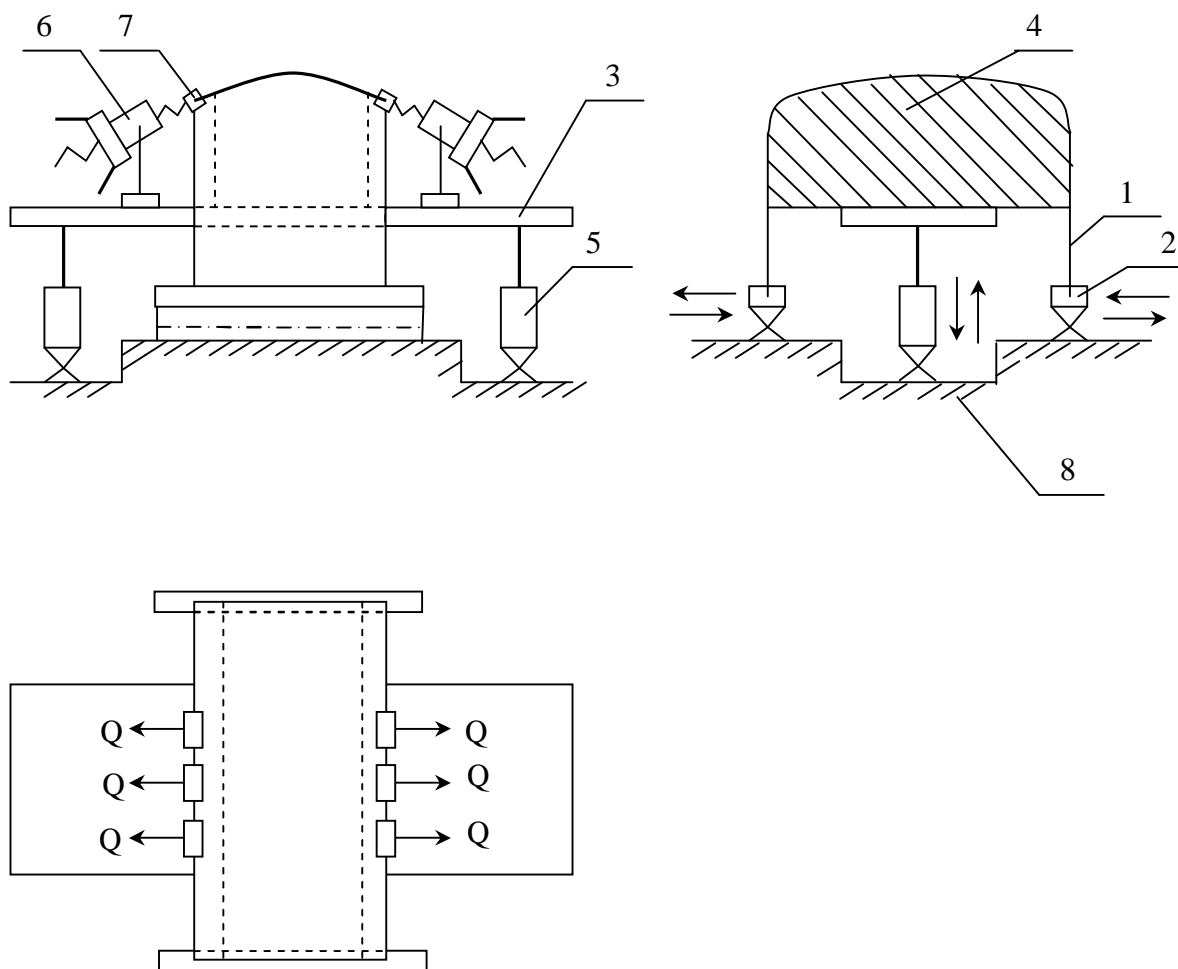$$Q_{\min} = \frac{(\sigma_y - \sigma_y^{\kappa p})Lh}{3}. \tag{13}$$

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Fig. 5. Schematic diagram of sheet-stretch press with lateral tension of sheet preform: 1- sheet preform; 2- jaws; 3-table; 4- sheet-stretch ram; 5-booster jack; 6-tightener; 7-lateral holder; 8-press bench.

As an example let's consider the light helicopter skin, which was stretched with lateral tension to prevent corrugations on the part dome using the OP-3 press. Skin overall dimensions: L=1600 mm; B=1500 mm, h=0,6 mm; R=2200 mm; material: Д16М (E=7200 kgf/mm^2; K=48 kgf/mm^2; n=0,25); deformation conditions: ε_x'=0,01; f=0,15.

Using the formulas (7)-(13) for calculations, we will obtain: B_K=1492,5 mm; B_C=1480,1 mm; γ_{max}=0,0166; T=4179,0 kgf; σ_y^{cr}=1,2kgf/mm^2; σ_y=8,7 kgf/mm^2; Q_{min}=2400,0 kgf.

The lateral stretching of the sheet preform allows to have this skin without any corrugations in dome zone.