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DETAIL DESIGN OF AIRFRAME PART

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PREFACE

The design of parts concludes the last stage of designing an aircraft - the technical project development. This stage consists of publishing all technical documentation that is necessary for manufacturing, assembling and mounting separate units and systems as well as the whole aircraft. Drawings of the aircraft assemblies as well as separate subassemblies and parts should be also made.

According to standards of the Unified Design Documentation System (ESKD) the part is a product that is made of the homogeneous material without assembly operations and coverings. The subassembly is a detachable or fast-joint connection of parts of the same functionality. The subassemblies are divided in two groups: the simple subassembly is the part connection that is carried out by a certain technological method (riveting, welding) and the complex subassembly is the connection of several simple subassemblies and parts.

The assembly is the connection of subassemblies and parts that create the complete construction. The assemblies are connected in a producer-factory at the stage of the final aircraft assembly.

Thus, according to the design logic the aircraft development starts with defining the outside contours and finishes with designing the aircraft parts.

And vice versa, the production starts with producing the parts that are connected in the simple subassemblies and, then the simple subassemblies are connected in the complex subassemblies and etc.

In the university the process of studying the design principles is carried out in accordance with the production logic: it starts with studying the part design and, and then it continues studying the design of more complex objects - subassemblies that include several parts of the different functionality and configuration, which are joined with one functional task (the balancing a concentrated force plays an important role of it). The final stage of the construction design is the development of the aircraft assembly.

After executing all laboratory works and a graduation work (for a final-year student) a student is ready to use the design logic almost at all stages of developing the aircraft project.

The aircraft parts can be classified by the functionality and their role in transferring the forces.

According to the functionality the parts are divided in:

– parts that are included in the aerodynamic contour. There are all elements of the aircraft skin, cowls and fairings;

– parts of the airframe, longitudinal and transversal elements;

– connection elements. There are hinge brackets of control surfaces, hatches and doors; parts of joint subassemblies; cranks and control system brackets.

– elements of power systems and mechanisms, landing gear parts, power cylinders and etc.

– fixing elements (bolts, screw-nuts, screws, rivets and etc.)

According to the role in transferring the forces the parts are divided in:

– load-carrying parts that are included in the load-carrying scheme. The internal stresses of the part elements are defined by the action of external forces.

– non-load-carrying parts that do not transfer loads. The cross sections of the part elements are defined by other design and technological considerations.

It should be noted that the total mass of these parts with the fixing elements can amount to the half of the mass of the aircraft construction.

This manual mainly considers tasks of designing parts of the connection element group - load-carrying brackets, cranks and fittings. These parts are usually made by methods of the hot stamping or casting with the following machining operations.

Nevertheless, most of recommendations for solving the design tasks can be used for designing the parts of other classified groups.

Generally, the design is the process of developing the technical documentation that provides manufacturing and maintaining the product.

The design process consists in searching the best solution based on a compromise between requirements of strength, the minimum mass and the decrease of the manufacturing complexity and cost under satisfying all maintenance requirements.

The search of the technical solution that satisfies the technical requirements is the informal and creative process. The experience, erudition and intuition of a designer play the important role.

There are obviously no general recommendations for solving the creative tasks. But some rules for searching the technical solution can be formulated.

At the first design stage a designer should estimate the possibility of executing the task at the expense of one of the known solutions (analogue or prototype).

The designer synthesizes the project at the expense of a combination of separate elements of the known solutions if at the first stage the solution wasn't found.

The designer should find a new invention solution if the previous two stages were ineffective.

This manual is intended to help students to make the first step of learning the design principles.

In spite of the seeming simplicity the execution of the part design project allows students to get acquainted with a sequence of stating and solving particular design subtasks. It is in essence a design school that should start the process of studying an inexperienced designer.

The designer defines the design sequence as his experience is accumulated. At first, when a student does not have enough experience it is recommended to use the following design sequence [20]:

1. The task analysis. The definition of the part functionality and work conditions, imposed restrictions and loading conditions. Developing requirements of the design part.
2. The engineering analysis of prototypes.
3. Developing design and manufacturing requirements of the part.

4. Choosing a connection method of the design part and mating parts; the balancing the design part.

5. Choosing fixing elements and bearings according to the connection method.

6. Developing 3-4 load-carrying part schemes according to the imposed restrictions.

7. The design and manufacturing and load-carrying analysis of the developed schemes with using the criterion "the load-carrying factor".

8. Choosing a design model and defining internal part stresses for the best load-carrying scheme.

9. Choosing a part material and part blank types in accordance with the work conditions, the manufacturing method and the internal stress values.

10. Defining dimensions of part element cross sections on the basis of the design estimation.

11. Choosing a shape of the cross sections, the working accuracy and the manufacturing method with taking into account the technological restrictions that are imposed according to the chosen manufacturing method.

12. Making a drawing of the part and plotting all necessary information (the dimensions and the technical requirements) on it.

13. Preparing an explanatory note that should consist all design stages.

It is appropriate to mention here that the general property of a design process is the iteration. During the project development it is inevitable to make changes - give corrections or more precise definitions to already made decisions, i.e. it is a return to the executed stages. But it is commonplace, so there is no reason to be confused. At the same time the proverb «the best is oftentimes the enemy of the good» works for the training design as the real design. In other words, the improvement of the operative structure by the iterative execution of design stages can be done if only all work finishes in due time.

1 THE TASK ANALYSIS

1.1 The part design role in the subassembly design

As mentioned above, the part development starts at the end of the design when the subassembly development is carried out. The design part and mating parts usually transform the applied concentrated force to distributed internal stresses in thin-walled elements of a regular zone of the construction.

The part design can be started when the load-carrying layout of the subassembly is defined and the geometrical and layout restrictions are applied on the part configuration. Also the cross sections and configurations of the regular zone elements should be defined [14].

The part is an element of a load transfer chain. The design of separate chain elements is impossible. The part elements that connect it with neighbor parts should be designed jointly with neighbor parts with taking into account their geometrical, layout and strength parameters.

It is necessary to discuss the construction and main parameters of the regular zone and all possible variants of the subassembly layout (the juncture of the design part and neighbor parts) with your professor before starting the part design. It allows making a more proved decision of the part configuration.

1.2 The general description of the part functionality

All part of the considered group can be divided in 3 groups:

– hinge brackets of control surfaces;

– control system cranks and support brackets;

– parts of joint subassemblies.

Parts of the first group combine into hinge subassemblies (Figure 1, 2). Ailerons, trimmers, interceptors, some lift devices and also hatch leafs and doors are connected with fixed aircraft parts by the brackets articulated with each other. They provide the necessary angles under the minimum rotation drag. The bracket shapes depend on connection assembly constructions in joint zones.

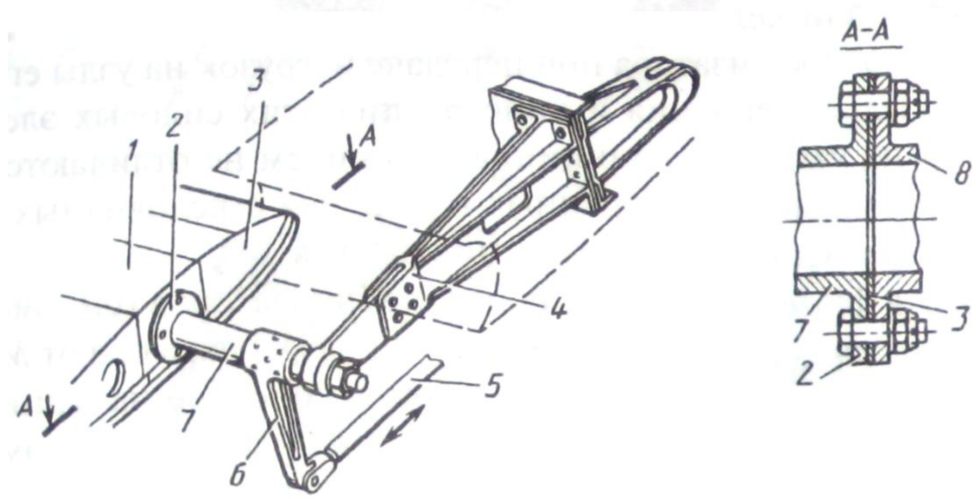


Figure 1 – The elevator control:
1 – the elevator, 2 – the load-carrying rib of the stabilizer, 3 – the elevator fulcrum, 4 – the hinge bracket, 5 – the control rod, 6 – the crank-pylon.

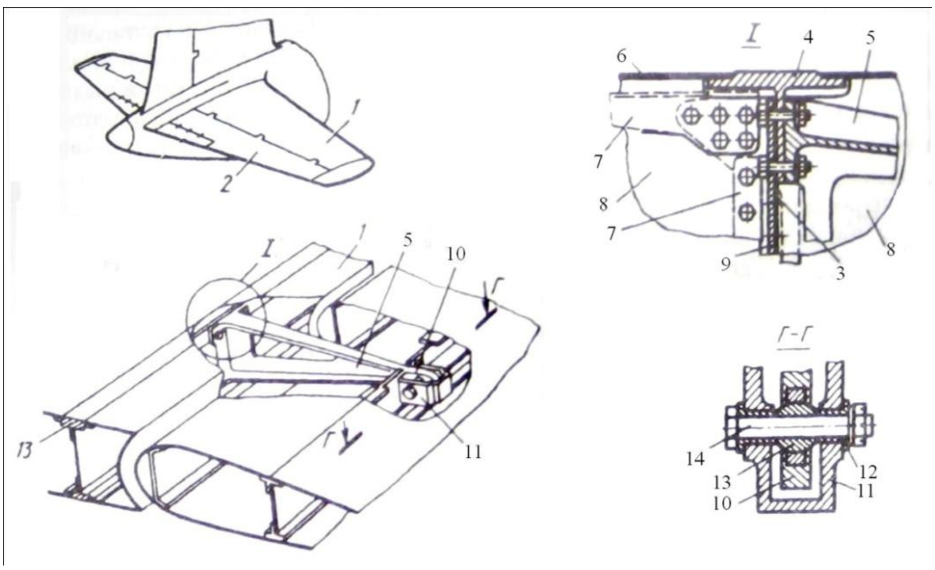


Figure 2 – The hinge subassembly of the elevator:

1 – the stabilizer, 2 – the elevator, 3 – the load-carrying rib of the stabilizer, 4 – the stabilizer spar, 5 - the elevator spar, 7 – the bearing, 8 – the stabilizer bracket.

Generally, the control surface hinge brackets lie in the plane of two- belt flat beams (the ribs of the moving and fixed control surface parts); also they are the load -

carrying continuation of these beams. Taking into account that the brackets are connected as the «ear-fork», which participates in transferring the concentrated force, the design scheme of these parts is an outrigger that is restrained on the rib end and, also it has the concentrated force on the free end. This part is made in the form of a flat beam with convergent belts, a frame or a three-link girder; and it is often produced by the hot stamping method.

The joint is loaded with reactions of the aerodynamic force that acts on the control surface during the flight.

Authors recommend you to get acquainted with samples of these parts in the room of aircraft constructions. There are the hinge brackets of elevators and ailerons of the aircrafts Tu-4, Tu-16, Tu-95, IL-28, «Airacobra», rudders of the aircrafts IL-28, MiG-15, Yak-26, doors of the landing gear compartment Tu-4, Su-15. All samples are notable for the variety of their design and technological solutions.

The control system cranks and their support brackets are intended to change directions of rods motion. The directions of the rods motions define a crank shape and an angle between levers. If levers lie in the same plane the crank is made by the hot stamping method. Often it is necessary to change not only the direction, but and the plane of the rods placement. These cranks are made by the casting or machining operation methods. Or this crank can be assembled from separate elements by the welding method.

In the junction the crank is usually made in the fork form, where the rod with the ear is inserted. The bearing with a salient inner race is inserted in this ear.

Every crank lever is a beam that is restrained in the hub with the concentrated force that is applied from the rod direction. The crank hub construction provides lack of a backlash along the fulcrum and takes the unnormalized force component from the crank plane. Two bearing in the hub provide it. It is important to ensure the coincidence of axes and the axes parallelism for lack of jamming while the crank turns.

The control rod load on the crank is set up after estimating the control kinematics.

The cranks base on the brackets that should have their own rigidity and base on the load-carrying elements of the airframe, because it is related to the rigidity of all control linkage. The brackets usually have the space form, and they are made by the casting with the following machining operations. The brackets are loaded from the direction of the crank that is inserted in them.

You can find samples of the cranks and brackets in the room of aircraft constructions.

It is useful to view the assembled linkage of the fuselage aft portion of the aircrafts Yak-26, MiG15 and of the wing of the aircrafts Il-28, Yak-25, MiG-15.

The parts of the joint subassemblies are set up in places of aircraft assembly connections. There are subassemblies of the connections between the wing, the tails and the fuselage, attachment points of the landing gear. The big values of the normal force and tangential force of the belt and the spar wall correspondingly are transferred through these parts. Such parts are made in the form of a shank with an ear, and they are made of high-strength materials by the machining operations from the hot-stamp blanks.

You can find these parts on the wings of the aircrafts « Douglas A-20», « Super Aero», MiG-15, Su-15.

2 THE GENERAL REQUIREMENTS OF THE PART CONSTRUCTION

The technical requirements of the part are defined by a designer before the design starts. The requirements define the part properties, but the requirements are determined by the part functionality and work conditions with taking into account results of design and technological and work particularities of the prototypes that are in the room of aircraft construction.

When you will execute your task, it is enough to make two groups of the requirements: 1 - functional and 2 -manufacturing and technological.

The functional requirements comprise the part functionality, the requirements of the part reliability and life. Also there are geometrical, kinematic, strength and rigidity restrictions.

The manufacturing and technological requirements are interrelated with the economic requirements. The manufacturing cost decreases under the constant work characteristics and the minimum mass directly influences on the aircraft cost efficiency.

The requirement of the minimum mass is priority for the design of the aircraft parts. It is satisfied by the rational load-carrying part scheme, the appropriate constructional material and its calculated failing (acceptable) stresses. The increase of the part strength and rigidity should be done at the expense of refining the part shape and applying surface strain-hardening technologies (not of the increasing the part cross sectional area).

The manufacturing and technological requirements are satisfied by satisfying a number of more particular requirements. The part manufacturability is defined by the right choice of the part material and shape, the design and technological bases and the rational choice of the limit deviations and the surface roughness. The designer should design the part according to the particular technological process and tools that will be used for manufacturing the part. The well- know technological processes (the hot stamping, the casting) require to meet some conditions of choosing constructional shapes and some restrictions of the minimum part dimensions. It is necessary to take into account the restrictions while defining the part dimensions of the required strength.

The requirement of the design solution succession suggests using the approved approaches and methods of the part design as the already developed and tested part elements. It often allows to significantly decrease the design time. However, it should be mentioned that during executing your project you should bravely use new design and manufacture technologies.

The designer should anticipate the possibility of executing the part mass fixing while designing it, carrying out the inspection operations of setting the support elements and lubricating the conjugate places with the mating parts while assembling the parts for providing the manufacturability.

The part reparability requirement is satisfied by using the limit deviations of surfaces that are conjugated with other parts, which provide interchangeability and usage of repair limit deviations as it is necessary.

The reliability and durability requirements are satisfied by providing the local strength, the right choice of the material and the failing (acceptable) stresses, the usage of the surface hardening technologies and the antirust coverings.

3 THE INITIAL DATA

The initial data of the part design is defined during the process of developing the subassembly that consists of this part.

First of all, this data describes the part functions as the component of the subassembly so it will help you to make some design schemes of subassembly parts joints.

The layout restrictions and the configuration of the surrounding elements apply the size restrictions on the part and define joint surfaces and connection dimensions.

Kinematic restrictions define a degree of freedom of the part and positions of its elements according to the mating parts.

The data about loads is usually presented in the form of values and directions of the concentrated forces that act on the part from outside in normalized calculating cases.

Analyzing the work conditions can find out the information about possibilities of emerging the unnormalized loads on ground or in air, so it should be considered during the design process.

The understanding of the initial data is the complicated design task. And if this task is successfully solved the design time decreases and the design quality increases.

4 BALANCING THE PART. CHOOSING THE NORMALS

One of the main functions of the subassembly part is to take and transfer applied external forces to balance them. Obviously, the self-balancing system of the forces, which act on the part, consists of the external forces applied to it and the system of adjacent parts reactions. We can mentally insulate the part from the subassembly, apply the system of the external forces and support reactions to this part and, then, this part can be designed separately from the subassembly.

The scheme of balancing the part is developed according to the chosen method of connecting the subassembly parts and the base, which is usually the assembly frame. There are different types of connecting the parts with the bases and the balancing schemes in Figures 3, 4, 5.

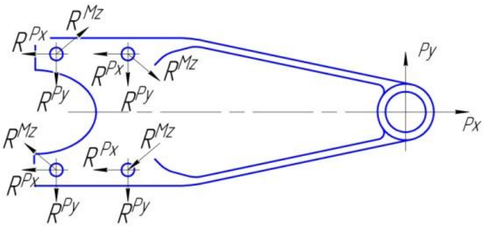


Figure 3 – The scheme of balancing the bracket (Figure1, the pos. 4)

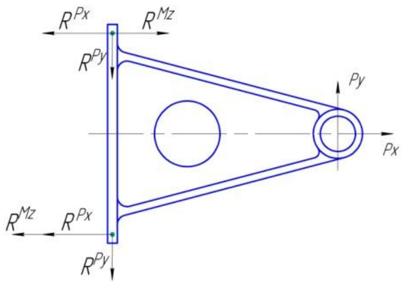


Figure 4 – The scheme of balancing the bracket (Figure 2, the pos. 8)

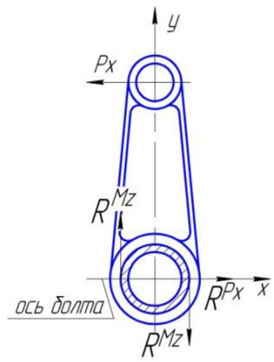


Figure 5 – The scheme of balancing the crank on the shift (Figure 1 the pos. 6)

From the Figures we can see that the connection type influences on the loading conditions of the fixing elements (shear, shear with tension) so it defines their dimensions and type.

Choosing the normals is rationally carried out before starting the design study of the part. In this case coupling sizes of standard elements (rivets, bolts and bearings) will be the geometrical restrictions of the part elements dimensions.

Selection of fasteners made of standard parts

Selection of fasteners made of standard parts according to the OST 1.21100-80 [15]. The extracts from [15] are necessary for executing the tasks, and they are given in the Appendix 1. It is necessary to follow the recommendations from [5] when you choose the dimensions of the fixing elements.

If the design part has bearings you can choose them by values of the failing stresses using [3].There are the extracts from [3], which are necessary for executing the tasks, in the Appendix 2.

You should take into account the active load and peculiarities of bearing work conditions in aircraft constructions when you choose the bearings. The bearings that are given in the aviation standards have the noticeably less rotation frequency and higher requirements of decreasing the friction.

You can follow our recommendations when you choose the bearings. The single-row radial bearings, which are able to take some unnormilized axial load, are used for connections that do not have the misalignment (fastening the control cranks on the axle). Their advantage is the minimum rotation drag. If there is no other way to protect a bearing from the external action the bearings with shields are used.

The radial, spherical single - and double-row bearings are used for the connections that may have the misalignment of the inner race according to the outer race (fastening the control rods to the cranks, the rudder hinge and etc.). These bearings take some axial load. The swivel spherical bearings are used for big radial loads with the misalignment.

5 DEVELOPING THE VARIANTS OF THE LOAD-CARRYING SCHEME

An aim of this stage of designing the part is to fundamentally provide transferring the forces from places of their application to places of balancing them. This aim can be achieved in different ways; the design of the functional part construction (at the scheme level) is carried out on basis of the contrastive analysis of the variants that satisfy the already made requirements.

You should follow the general recommendations given below for developing the variants and making their comparison:

– the forces should be transferred by the shortest way;

– the forces should be transferred by tension, compression and shear (they are more advantageous in the mass aspect); you should try to avoid flexural elements;

– the volume should used to the maximum for increasing the part constructional height.

The variants of the load-carrying scheme are made in the form of sketches (a sketch is a drawing that is made by hand with keeping the approximate scale). The dimensions of the part elements (ears, bases and a part body) are defined on the basis of the prototypes analysis that was made earlier. But the sketches also require taking into account the majority of the part requirements, especially at this stage - the technological and maintenance requirements.

Consider the elements, which can be included in the load-carrying scheme of the part.

Rod is an element that works in the axial forces of tension and (or) compression. The part that is made of rods is an elastic, flat or space truss with a swivel of truss joints. In some cases, when the rods axes, which converge at a joint, do not intersect at one point (the joint centre), you have to consider the axial forces of tension and compression and also local bending moments. At that, the truss rods work in the transverse-longitudinal bending. The truss parts, which have approximately the equal dimensions by two (flat) or three (spatial) axes, usually benefit.

For small constructional heights (the side proportion is 2:1 or more) it is appropriate to use beam structures that can take loads, which act in their plane; at that, the beam wall works in shear and the belt works in tension-compression. The belts stresses and cross-sections are not constant and increase as the design section moves off the point of applying the external force to the part and approaches to balancing places.

A number of parts can be made in the form of a flat wall that transfers the shear force and the force of tension-compression in its plane. When using the wall, you should be sure that the part is not loaded by forces that act from the plane of this wall.

Large parts of the complex shape can be done in the form of a frame that works in bending, shear and tension in its plane.

After making sketches of three - four different load-carrying schemes of the part, you should evaluate each of them with respect to meeting the part requirements. Also you should give a comparative evaluation of methods of manufacturing each part with taking into account the material and labour-intensiveness.

The final decision of the load-carrying scheme can be made according to the results of the comparative analysis with using the high-precision mathematical models. A comparison criterion is the load-carrying factor that is a special characteristic, which concurrently takes into account the value and extension of the internal stresses of the part, so you can estimate the relative efficiency of the developed load-carrying schemes.

6 CHOOSING THE RATIONAL LOAD-CARRYING SCHEME ACCORDING TO THE "LOAD-CARRYING FACTOR"

It should be reminded, that we consider the design of "load-carrying" parts, whose main function is to take and transfer the loads (external load action). It means that most of the part parameters that influence on part properties (the material, the shape, the dimensions, the mass and etc.) are defined by their load-carrying work. The total mass of the load-carrying construction can be divided in two components: the first component is defined by the load-carrying work of the construction, and it can be called as the theoretical mass. The theoretical mass is the minimum mass of this construction variant that provides transferring the loads by this construction under the requirements of strength, rigidity and durability. The second component of the load-carrying construction mass is defined by other requirements; for example: the necessity of decreasing the labour-intensiveness of manufacturing this part, the economic requirements, the requirement of interchangeability, special physical properties, the increase of the part life and etc. The correlation between these two components is not discussed in this manual, but it should be mentioned one more time that the theoretical mass of the load-carrying construction depends on its load-carrying scheme. The load-carrying scheme is a set of load-carrying elements of the construction (in our case - the part) that define the main ways of transferring the loads. The load-carrying scheme is defined by types of load-carrying elements, their quantity, their spatial location and types of elements connection. Thus, each variant of the part has its own system of internal stresses according to the load-carrying scheme. This system provides transferring the external loads to places of their balancing. Obviously, these internal stresses will balance the external forces in each part section. It is shown in the Figure 6. The figure shows the loads that act on the control crank.

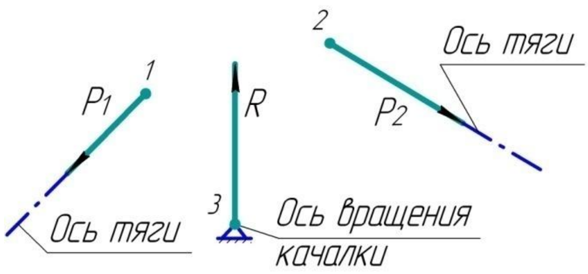


Figure 6 – The scheme of the loads that act on the control crank

In the Figure 7 (а, б) two possible variants of the load-carrying scheme of the crank are shown. (Of course, there are a lot of other variants of the load-carrying schemes and corresponding variants of the part designs.)

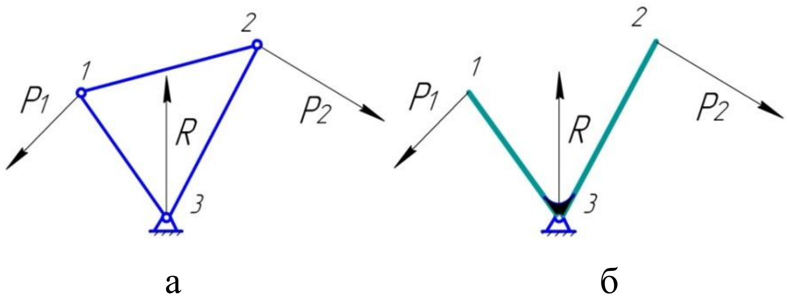
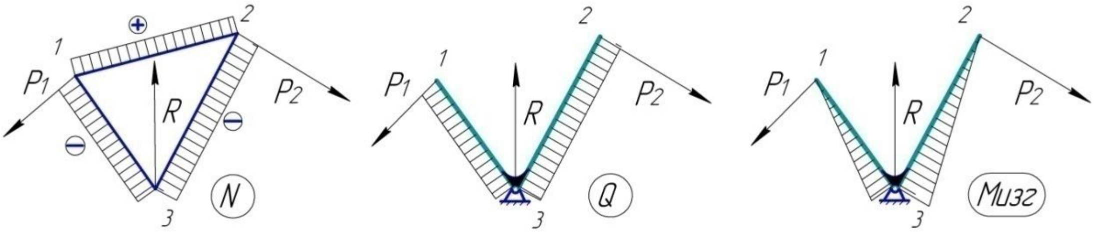


Figure 7 – The load-carrying scheme variants of the crank:

а – the truss, б – the frame

In the Figure 7*a* the load-carrying scheme is the flat three-rod truss.

In the Figure 7*a* the load-carrying scheme is the flat load-carrying frame that consists of two straight-line elements (levers) 3-1 and 3-2, which are connected by a moment joint at the point 3. Further this scheme will be called as a beam structure. In the Figure 8 the diagrams of forces and moments of the crank elements are shown for each scheme.



а б в

Figure 8 – The diagrams of internal forces and moments of the crank elements:
а – axial forces of the truss rods, *б* – the shear forces,
в – the bending moments of the levers-beams

To select the rational variant of the load-carrying scheme (consequently, the design shapes of elements) of the design construction (in our case, there is the part), it is necessary to compare variants by load-carrying factor values, which were calculated for each variant. The load-carrying factor is defined by the value of the internal stresses of the construction and their action extension (i.e. the extension of ways of transferring the external forces) [13, 19] and it is calculated as:

$$G = \int_V \sigma_{\text{прив.}} dv, \qquad (1)$$

where G – the load-carrying factor;

$\sigma_{прив}$ – the reduced stress– the stress of the single-axis stress state that is equal to the stresses, which act in infinitesimal construction volume dv, by the specific potential energy;

V – the total volume of the construction.

In the particular case, the load-carrying factor value of one truss rod is defined as the product of the rod stress modulus and the rod length; the load-carrying factor of all truss construction is defined as:

$$G = \sum_{i=1}^{i=n} |N_i| l_i \qquad (2)$$

where N_i, l_i – the stress and the length of a *i -rod*,

n – the number of the truss rods.

Formulas for calculating the load-carrying factor values of some standard elements are given in the Appendix 2.

The expression (2) of the truss construction shows the physical interpretation of the load-carrying factor - an integral characteristic of the load-carrying construction that simultaneously comprises the internal stress values of the construction elements (that transfer the external forces to places, where they are balanced) and the extension of the internal forces action (the extension of ways of transferring the external forces). It is evident from the expression (2) that the full-strength truss construction volume value of $V_{потр}$ (consequently, and the mass value) that requires the strength conditions can be defined by the known values of the load-carrying factor and strength characteristics of the constructional material.

For the equally stressed truss:

$$G = \sum_{i=1}^{i=n} |\sigma|\, F_i l_i = |\sigma| V.$$

(where F_i – the cross-section area of a i-rod).

If we assume that the failing stresses $\sigma_{разр}$ of all rods are equal:

$$V_{потр} = \frac{G}{\sigma_{разр}}, \qquad m_{равнопр} = \rho \frac{G}{\sigma_{разр.}}, \tag{3}$$

where m – the full-strength construction;

ρ - the constructional material density.

The expression (3) can be rewritten if we assume that the failing stress is the ultimate strength $\sigma_в$ of the material:

$$m_{равнопр} = \frac{G}{k_{уд.пр.}};$$

where $k_{уд.пр.}$ - the strength-to-weight ratio of the constructional material.

Similarly, the formulas of the required volume and mass of an arbitrary construction with the reduced stress and specific strain energy values, which are equal in all elementary volumes (points) of the construction, can be figured out from (1):

$$V_{потр} = \frac{G}{\sigma_{прив.}}, \qquad m_{потр.} = \rho \frac{G}{\sigma_{прив.}} \tag{4}$$

It is known that the internal stresses (and the load-carrying factor) of statically determinate constructions do not depend on the rigidity ratio of load-carrying elements. The internal stresses of statically indeterminate constructions are determined by the equilibrium conditions and the strain compatibility condition. The strain compatibility equations are a mathematical model that comprises the dependence of the internal stresses on the load-carrying elements rigidity. Extensive computational experiments have established the following remarkable property of the load-carrying factor: its value weakly depends on the rigidity ratio of load-carrying elements, and it is mainly determined by the load-carrying scheme. Thus, the cross-section areas of some load-carrying elements and their internal stresses may differ significantly (even several times) while the load-carrying values of the construction, on the whole, differ only by several percent [13, 19].

This property of the load-carrying factor and the related theoretical construction mass gives grounds to use the load-carrying factor value as a criterion for comparing the load-carrying scheme variants and choosing the best of them. Actually, it is clear from the expressions (3) and (4) that, under the specified (chosen, set) values of $\sigma_{разр}$ or $\sigma_{прив}$ the required construction volume is determined by the load-carrying factor, i.e. by the construction load-carrying scheme. Consequently, among construction variants, which differ from each other by load-carrying schemes, the minimum value of the required volume belongs to the variant that has the lowest value of the load-carrying factor.

It is remarkable that in this way the designer can choose the best variant by the criterion of the lowest value of the theoretical mass, having only information about the distribution of the internal stresses of each considered load-carrying scheme. If it is difficult to make a design model in the form of an ensemble of standard elements, whose methods of calculating the internal stresses are well-known and easy to carry out, finite-element models (FEM) are used with applying the available software that realize the finite-element method. In [20] you can find recommendations for creating FEM with a view to choose the rational variant of the load-carrying scheme of design parts.

The load-carrying factor has the dimension of work or energy, for example: [Newton*meter]. In this case, the load-carrying factor can be considered as a quantitative index of the load-carrying work efficiency of the construction (an index of its "load-carrying perfection "). The designer gets a powerful tool for choosing the rational load-carrying scheme variant of the design construction (part) under the specified initial data of the geometrical dimensions and external forces, when the load-carrying factor is used as the quantitative index of the load-carrying work efficiency. At the same time, the dimensional form of the load-carrying factor does not enable to compare, for example, the load-carrying work efficiency of parts that are similar or related to each other by the function and work conditions and differ from each other by the geometrical dimensions and (or) active external forces values. A scheme of a simple construction, which provides transferring the force *P* at the distance L along the force action direction, is shown in the Figure 9.

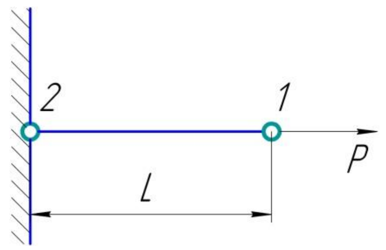


Figure 9 – Transferring the force along the force action direction

The comparison of the load-carrying work efficiency of the construction (or construction variants that have the different load-carrying schemes) is convenient to carry out with using the load-carrying factor "expense" of transferring the unit external force at the unit distance in place of the absolute values of the load-carrying factor. This dimensionless quantity is called as the load-carrying factor coefficient. It is denoted as C_G. So the load-carrying factor G of the construction, which transfers the given force P at the distance L, can be calculated as the product $C_G \times P \times L = G$. Obviously, if the value of the load-carrying factor G is known, the value of C_G can be calculated as:

$$C_G = \frac{G}{P \times L}. \qquad (5)$$

Summarizing the consideration given above that is related to an arbitrary construction, we can conclude that the load-carrying factor coefficient C_G is obtained as a quotient by dividing the load-carrying factor value by the product of the external force (the generalized force) and the construction linear dimension (the distance from the force application point to the point of balancing this force (the generalized length of transferring the force)).

The task specification and the load-carrying scheme variants, which provide transferring the force P to a support that is placed at the distance L from the force application point, are shown in the Figure 10. The distance is measured transversely to the force action direction.

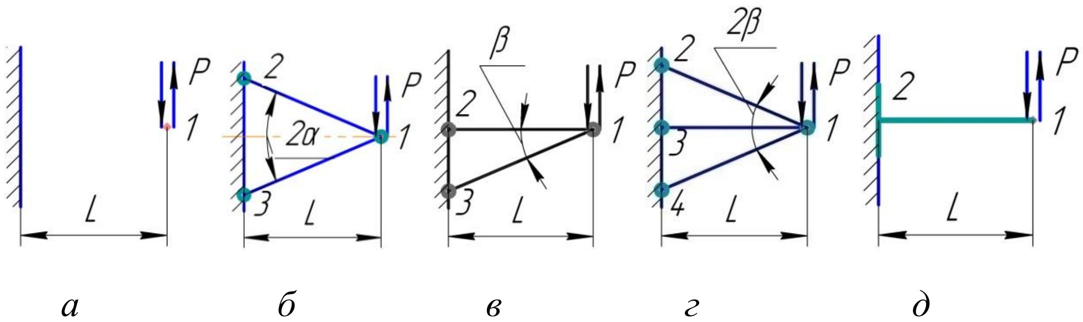


Figure 10 – The task specification and the load-carrying scheme variants:

а – the task specification; *б* –the two-rod symmetric truss;
в –the two-rod asymmetric truss; *г* – the three-rod truss; *д* – the outrigger

Obviously, all variants of brackets, which are shown in the Figure 8, have different values of the load-carrying factor. At least, it is easily proved by carrying out simple calculations.

The load-carrying values of the variants 10*б* – 10*г* are calculated by the formula (2), and it is necessary to use formulas from the Appendix 2 for the variant of a bracket of the beam load-carrying scheme 10*д*. The comparison of the load-carrying work efficiency of brackets and, consequently, their mass efficiency is convenient to carry out with using the load-carrying factor coefficient values that are calculated by the formula (5).

Consider the example of the symmetric bracket in detail. The construction symmetry makes calculations easier and increases the visibility of results without breaking, on the whole, community of approaches that are used for solving the task. The scheme of the initial task data is presented in the Figure 11. The area, which is intended for placing the bracket, is limited by the dotted line.

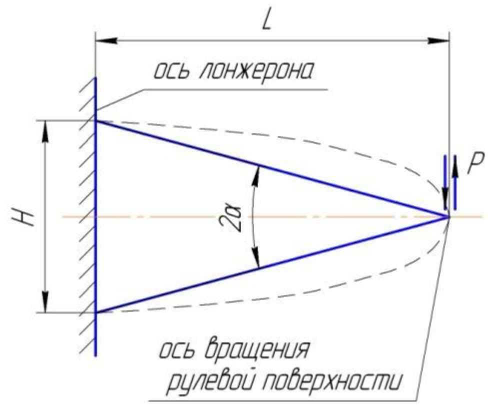


Figure 11 – The initial data for designing the bracket

We will consider two variants of the bracket: the two-rod truss (Figure 10*б*) and the outrigger Figure 10*д*). The comparison of the load-carrying work efficiency is carried out by the values of the load-carrying factor or load-carrying factor coefficient.

The truss load-carrying factor:

$$G = 2/N/l = 2 \times \frac{1}{2} \times \frac{P}{\sin\,\alpha} \times L \times \frac{1}{\cos\,\alpha} = \frac{PL}{\sin\,\alpha\,\cos\,\alpha} = \frac{2PL}{\sin\,2\alpha};$$

(i.e. $\sin\alpha\cos\alpha = \frac{1}{2}\sin 2\alpha$).

The bracket transfers the force P at the distance L. The load-carrying factor coefficient is

$$C_G = \frac{G}{PL} = \frac{2PL}{\sin\,2\alpha PL} = \frac{2}{\sin\,2\alpha}.$$

The load-carrying factor of the outrigger (Figure 10 *д*) is calculated by the formulas that are given in the Appendix 2. The load-carrying factor of the thin-walled outrigger section is calculated by the formula below. The length of this section is *dl*.

$$dG = 2\frac{|M|}{h}dl + \sqrt{2{,}6}|Q|dl, \qquad (6)$$

where M – the bending moment,

Q – the shear force,

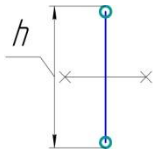
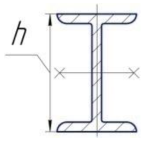
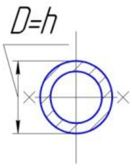
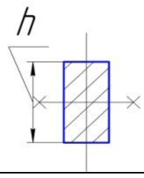
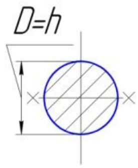
h –the outrigger height of the section.

In real constructions the decrease of a distance between belt cross sections centres of gravity is taken into account by using the effective beam height h in comparison with the cross section geometrical height:

$$h_{эф} = \varkappa h,$$

where the coefficient of the cross section shape $\varkappa \leq 1$. The coefficient value of the given cross section area of the beam depends on the cross section shape of this beam. The coefficient values of $\varkappa$ of some standard cross section shapes are given in the Table 1.

Table 1 – The coefficient values of $\varkappa$ of some standard cross section shapes (bending a beam according to the axis x-x)

№ cross section shape	1 	2 	3 	4 	5 
Type of the cross section shape	Ideal I-beam	Real I-beam	Round ring	Rectangular	Round solid
Coefficient of the cross section shape $\varkappa$	1,0	0,75	0,5	0,35	0,25

It should be mentioned that the real resisting bending moment of the ideal I-beam depends on the cross section dimensions (under the given area and height *h;* first of all, these dimensions are the thickness and width of the flanges-belts. Thus, the value of $\varkappa$*,* which is given in the Table 1, is approximate.

The load-carrying factor of the whole construction is calculated by integrating the expression of *dG* along the beam. To perform these calculations, we introduce a coordinate system and set a beam height, which is generally variable along the bracket length. In the Figure 12 three examples of possible variants of changing the beam-bracket height are shown: the beam height is constant and equal to the theoretical height H; the beam height linearly varies from zero (theoretically) to H, the beam height follows the theoretical contour of a fixed mating assembly.

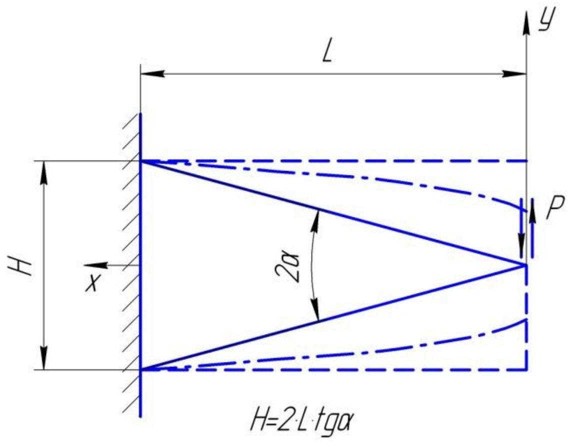


Figure 12 – The variants of changing the beam height:

- - - - the beam of the constant height, -·-·-·-· the theoretical contour of the assembly, the height linearly changes

In the Figure 13 the diagrams of the shear forces and bending moments of the cross sections are shown for the case, when the external force acts downward.

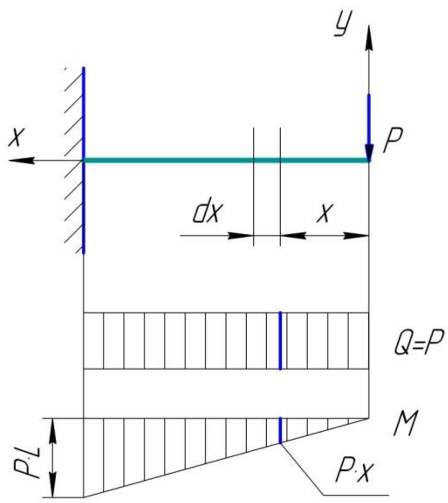


Figure 13 – The shear force and bending moment diagrams of the bracket that has the beam load-carrying scheme

Firstly, let's consider the beam-bracket of the constant height.

For the beam section of the length *dx* (Figure 10) the expression of the load-carrying factor *dG* is:

$$dG = 2\left|\frac{P}{H}\right| xdx + \sqrt{2{,}6}Pdx.$$

The load-carrying factor value of the whole beam is calculated by the following expression with taking into account the beam height $H = 2Ltg\alpha$:

$$C_G = \int_l dG = \int_0^L 2\left|\frac{P}{H}\right| xdx + \int_0^L \sqrt{2{,}6}Pdx = PL\left(\frac{1}{2tg\alpha} + \sqrt{2{,}6}\right).$$

The beam transfers the load *P* at the distance *L*, and the load-carrying factor of this beam is:

$$C_G = \frac{G}{PL} = \frac{1}{2tg\alpha} + \sqrt{2,6}.$$

The scheme of the internal stresses of the cross section of the beam with inclined belts is shown in the Figure 14.

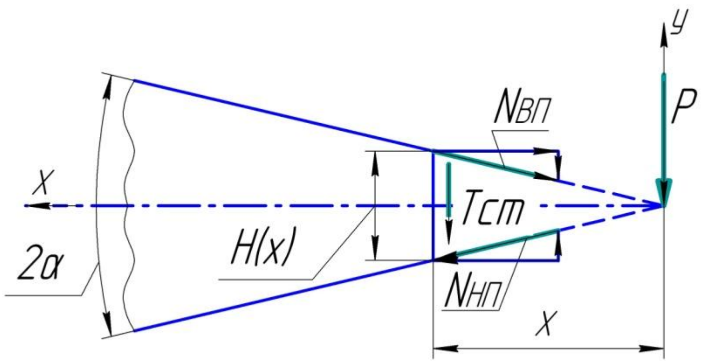


Figure 14 – The internal stresses of the cross section of the beam with inclined belts

Thus, the beam with inclined belts (under the angle α to the beam axis):

$$dG = 2\left|\frac{M(x)}{H(x)}\right|\frac{dx}{\cos\alpha\cos\alpha} + \sqrt{2,6}(P - 2\left|\frac{M(x)}{H(x)}\right| tg\alpha)dx. \quad (7)$$

Here $M(x) = Px$ $H(x) = 2xtg\alpha.$

Substituting these expressions in (7) and integrating, we obtain:

$$G = \int_0^L \frac{2Px}{2xtg\alpha\cos^2\alpha}dx + \int_0^L \left(P - \frac{2Px}{2xtg\alpha}tg\alpha\right)dx = \frac{PL}{\sin\alpha\cos\alpha} = \frac{2PL}{\sin 2\alpha}.$$

Obviously, the second summand is equal to zero, and the load-carrying factor is identically equal to the load-carrying factor of the symmetric two-rod truss. In this case, the beam wall is unnecessary, and beam transforms into the two-rod truss. It is correct for the real construction of the bracket, when the gravity centre lines of the truss rods cross sections (rods axes) intersect at the point of the external force application P. In practice the constructions of the beam brackets, in which this condition is not met, are more often used. At that, two variants are available: the axes of the beam belts intersect at the distance, which is less L (in front the ear centre), from the attachment, or at the distance, which is more L (behind the ear centre), from the attachment. For these cases the contour schemes of belts axes of the beam bracket are shown in the Figure 15.

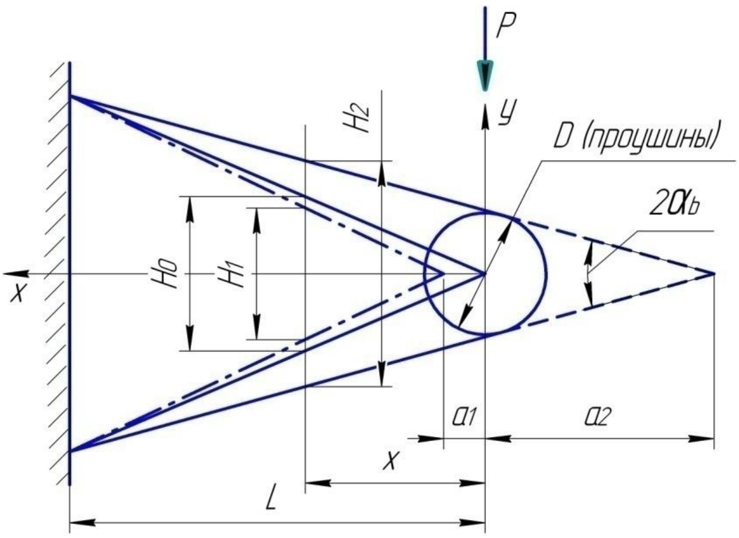


Figure 15 – The contour schemes of belts axes of the beam bracket:

—— The belts axes intersect at the ear centre (the variant *a*),

-·-·-·- The belts axes intersect in front the ear centre (the variant *б*),

- - - - The belts axes intersect behind the ear centre (the variant *в*)

Let's compare the variants by the load-carrying factor value and assume that the beam is the ideal I-beam.

Let's figure out the belts stresses of the beam cross sections *б* and *в,* which are located the distance x from the ear centre. For this, the values of the beams heights of this cross section should be defined. The values of the beams *б* and *в* are correspondingly:

$$H_б(x) = 2(x - a_1)tg\alpha_б; \quad H_в(x) = 2(x + a_2)tg\alpha_в.$$

The stress projections of the belts N_x, which are parallel to the bracket axis and balance the bending moment, are

$$N_{xn}^{б} = \frac{P \times x}{2tg\alpha_{б}(x - a_1)}; \quad N_{xn}^{в} = \frac{P \times x}{2tg\alpha_{в}(x + a_2)}.$$

The total normal stress, which acts along the belt axis, is:

$$N_x^{б} = \frac{N_{xn}^{б}}{cos\alpha_{б}} = \frac{P \times x}{2tg\alpha_{б}cos\alpha_{б}(x - a_1)} = \frac{P \times x}{2sin\alpha_{б}(x - a_1)};$$

$$N_x^{в} = \frac{N_{xn}^{в}}{cos\alpha_{в}} = \frac{P \times x}{2tg\alpha_{в}cos\alpha_{в}(x + a_2)} = \frac{P \times x}{2sin\alpha_{в}(x + a_2)}.$$

The length of the inclined belt section in the segment *dx* along the bracket axis is:

$$dl = dx\frac{1}{cos\alpha},$$

($\alpha=\alpha_б$ or $\alpha=\alpha_в$). Thus, the value of *dG* of the belts for each variant is:

$$dG_n^{б} = 2\frac{P \times x}{2sin\alpha_{б}cos\alpha_{б}(x - a_1)}dx = \frac{2P \times x}{sin2\alpha_{б}(x - a_1)}dx.$$

Similarly,

$$dG_n^{в} = \frac{2P \times x}{sin2\alpha_{в}(x + a_2)}dx.$$

And the load-carrying factor values of the belts in the segment, which is free from the D-diameter ears, are:

$$G_n^{б} = \int_{D/2}^{L} \frac{2P \times x}{sin2\alpha_{б}(x - a_1)} dx; \quad G_n^{в} = \int_{D/2}^{L} \frac{2P \times x}{sin2\alpha_{в}(x + a_2)} dx.$$

It is necessary to tale into account the wall work and its load-carrying factor. The part of the shear force, which is balanced by the shear stresses of the wall Q_{cm}, is:

$$Q_{cm}^{б} = P - 2N_{xn}^{б} tg\alpha_{б}; \; Q_{cm}^{в} = P - 2N_{xn}^{в} tg\alpha_{в}.$$

Substituting the expression for $N_{xn}^{б}$, $N_{xn}^{в}$, we obtain:

$$Q_{cm}^{б} = P - 2\frac{P}{2tg\alpha_{б}} \times \frac{x}{x - a_1} tg\alpha_{б} = P\left(1 - \frac{x}{x - a_1}\right) = -P\frac{a_1}{x - a_1}.$$

The "minus" of the final expression of $Q_{cm}^{б}$ shows that the shear force of the wall acts on the considered bracket section in the opposite direction to the active external force *P*. Consequently, in this case, the stresses of the bracket belts will decrease with increasing the coordinate values of *x*. Evidently, the modulus of the value of $Q_{cm}^{б}$ should be used for calculating the load-carrying factor of the wall, i.e. the load-carrying factor is severely positive.

$$Q_{cm}^{в} = P - 2\frac{P}{2tg\alpha_{в}} \times \frac{x}{x + a_2} tg\alpha_{в} = P\left(1 - \frac{x}{x + a_2}\right) = -P\frac{a_2}{x + a_2}.$$

In this case, the sign $Q_{cm}^{в}$ is positive, and the shear force of the wall acts in the same direction to the active external force *P,* the stresses of the belts will increase with increasing the coordinate values of *x.*

Now the wall expressions $dG_{ст}^{б}$ and $dG_{ст}^{в}$ are correspondingly:

$$dG_{cm}^{б} = \sqrt{2{,}6} Q_{cmб} dx = \sqrt{2{,}6} P \frac{a_1}{x - a_1} dx;$$

$$dG_{cm}^{в} = \sqrt{2{,}6}Q_{cmв}dx = \sqrt{2{,}6}P\frac{a_2}{x + a_2}dx.$$

The load-carrying factor values of the walls are defined by integrating the previous expressions in the segment form *D/2* to *L*:

$$G_{cm}^{б} = \sqrt{2{,}6}P\int_{D/2}^{L}\frac{a_1}{x - a_1}dx;$$

$$dG_{cm}^{в} = \sqrt{2{,}6}P\int_{D/2}^{L}\frac{a_2}{x + a_2}dx.$$

The expressions of the load-carrying factor of the brackets of the last two variants contain the initial geometric parameters L and H, as well as other parameters depending on the conditions of the task: the ear diameter, which is determined by the active load, the bearing dimension and the chosen bracket material; the distances a_1 and a_2, which are also dependent on the ear diameter and other conditions. The comparison of these variants in the general form is difficult to carry out. Using the obtained expressions, you can make the calculations for each case and obtain important results. The design formulas, which are obtained by integrating the expressions of the load-carrying factor of the walls and belts for the variants *б* and *в*, are given in Appendix 4 to simplify these calculations. The Table 2 shows only data for the comparative analysis of the advantageous use of two variants of the bracket load-carrying schemes: the two-rod symmetric truss and the beam of the constant height. Also in the Table 2 the load-carrying coefficient values of *G* are given as the criterion for the comparison.

The Table 2 – The data for the comparative analysis of the variants of the bracket load-carrying

The truss, the angle α,	5	10	15	30	45

degree					
The beam, *L/H*	5,714	2,836	1,866	0,866	0,500
C_G of the truss	11,516	5,843	4,000	2,310	2,000
C_G of the ideal I-beam	7,327	4,445	3,478	2,478	2,112
C_G of the real I-beam	9,232	5,389	4,100	2,767	2,279

It is seen from the Table that the load-carrying factor coefficient of the beam is significantly less than the load-carrying factor coefficient of the truss if values of α are small, i.e. values of the ratio of the beam length to its height are sufficiently big; so in this case it is advantageous to use the beam constructions. The load-carrying factor coefficient of the truss becomes smaller, when the angles of inclination of the rods α are sufficiently big. In real bracket constructions the lower limits of α are often located in the zone of competitive values for truss and beam load-carrying schemes of brackets. Note that the evaluation of the truss is correct if the rods axes intersect at the ear centre.

While designing complex-shaped parts, such as flat parts with a large number of external forces application places or spatial parts, the finite element model are made for comparing the design variants (load-carrying schemes). The calculation of the FEM stress state is carried out, and for each i - finite element the load-carrying factor value of G_i is calculated:

$$G_i = \sigma_{прив.} V_i,$$

where $\sigma_{прив.}$ – the reduced stress of an i -element ;

V_i – the volume of this element.

The load-carrying factor values of G of the whole FEM, which consists of n elements, are defined by the simple summation of the values of G_i:

$$G = \sum_{i=1}^{i=n} G_i.$$

The choice of the best variant according to the criterion of the part mass can be made by the load-carrying factor values of the appropriate variants. At the same time, it is always useful to calculate values of the load-carrying factor coefficient (the dimensionless specific characteristic) that is the load-carrying perfection index of the construction.

7 CHOOSING THE PART MATERIAL

The material choice is the important factor for providing the minimum part mass under the design conditions that are set up by the technical requirements. These are the part life, the work temperature, the nature of the force application and the environment conditions.

Consequently, the applied materials should meet the following requirements: the high strength-to-weight ratio under static stresses, the high fatigue resistance, the incorrodibility, the heat-resisting quality, the deformability, the machinability and a reasonable price.

The criterion of choosing the material to a first approximation can be characteristics of the strength-to-weight ratio under different types of loading:

$\frac{[\sigma]_p}{\rho} = \frac{\sigma_в}{\rho} \prod_{i=1}^{i=n} k_i$ – tension; $\frac{[\sigma]^{3/2}}{\rho}$ – bend; $\frac{[\tau]_p}{\rho}$ – shear

Here $[\sigma]_p$, $[\tau]_p$ – the calculated acceptable (failing) stress of the material under the specified calculating conditions,

ρ - the density,

k_i – correcting coefficients, which take into account the influence of the calculating conditions on material properties.

The coefficients k_i take into account:

– The material fatigue resistance that characterizes the speed of occurring the structural damages of the material that is subjected to cyclic loading, and also it characterizes the speed of broadening the occurred cracks;

– The material ability to work under the high temperatures of the environment that occur during the maintenance;

– The influence of the applied manufacturing method on the material characteristics.

In practice the coefficient values are defined by experiment. When you start to execute this work, you should define the value of k_i by the material characteristics that are given in the aircraft material reference book [7], and then approve it by the professor.

The problem of choosing the material is significantly simplified if the manufacturing method of the part blank (casting, hot stamping, welding or mechanical operation) is known in advance, i.e. it narrows the range of acceptable materials. The chosen material, in its turn, narrows the range of potential manufacturing methods.

The heat treatment method, which defines mechanical characteristics of the part material, is assigned concurrently with choosing the material and substantiating the calculated acceptable stresses. The information of the chosen heat treatment method should be plotted on a drawing in the section "Technical requirements".

To a first approximation the material can be chosen by characteristics that are given in the Appendix 4. However, the final solution can be made only with taking into account all material characteristics, which are given in [21].

8 THE DESIGN ESTIMATION OF THE PART

The design estimation is made with a view to defining the dimensions of the part cross sections in compliance with the strength conditions, and it is coherently carried out for each part element according to the chosen design scheme of each dangerous cross section. Each design cross section should have a sketch that shows its location in the part and shape. The methodology of executing the design estimation is shown on the bracket example.

In most cases the bracket is a beam of a variable height or a truss with a base that is clamped or hinged in two joints. In more complex constructions it can be a combination of these two schemes.

The typical feature of the beam bracket is the wall that transfers the shear force to the part base places and work in shear (Figure 16).

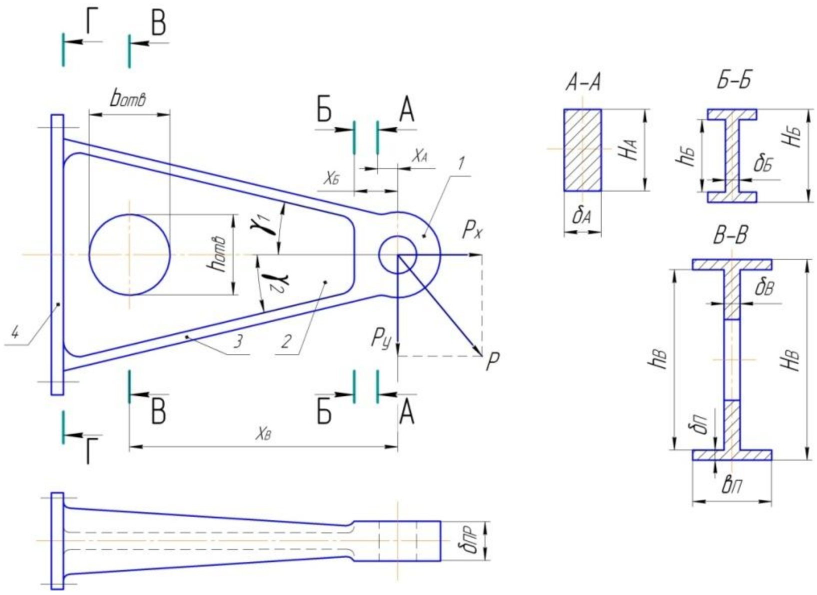


Figure 16 – The beam bracket:

1 – the ear, 2 – the wall, 3 – the belt, 4 – the base

In the truss bracket (Figure 17) the external load is transferred by tension/compression of the belts, the wall transforms in vertical ribs that support belts from the stability loss.

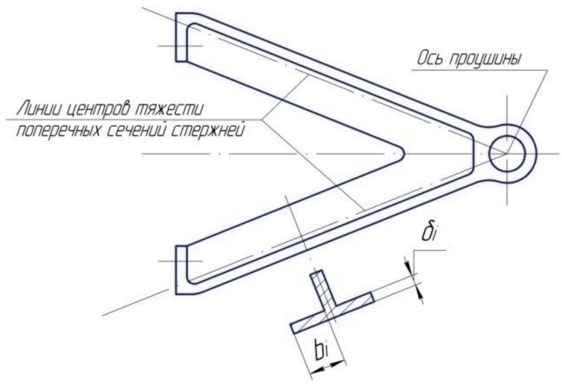


Figure 17 – The truss bracket

The estimation is rationally carried out in the sequence that is parallel to the part development:

1) Choosing the standard elements.

The design estimation of the bracket (as of every part) starts with choosing the standard elements (bolts, bearing, hubs and etc.) that are included in the joint. The methodology for choosing these elements is given in [5].

2) The ears estimation (Figure16, the position 1).

In most cases the brackets have an ear or a fork. The features of estimating the ears and forks are given in [8, 17].

3) The estimation of the zone, in which the ear transforms into the part body (Figure 16, the cross section A-A).

In general case this zone has a rectangular cross section that works in bend form the force P_y and tension or compression from the force P_x.

The strength conditions for this case:

$$\sigma_A = \frac{M_A}{W_A} + \frac{P_x}{F_A} \leq [\sigma]_p \qquad (8)$$

σ_A, M_A, W_A, F_A – characteristics of the cross section A-A: correspondingly the normal stress, the bending moment, the resisting bending moment and the cross section area.

From (8) with taking into account the Figure 16:

$$\frac{P_y \cdot X_A}{\frac{\delta_A \cdot H_A^2}{6}} + \frac{P_x}{\delta_A \cdot H_A} \leq [\sigma]_p \qquad (9)$$

It is necessary to define the height H_A and the thickness δ_A from the inequation above. It can be made by using one of the dimensions. For example, the height H_A can be set up according to the belts position in the chosen load-carrying scheme, or the cross section thickness can be set up a bit less than the ear thickness δ_{np} (Figure 16) for providing the smooth machining its side faces. It is usually taken that $\delta_A = [\delta_{\text{пр}} \ldots (\delta_{np} - 3)]$ mm.

The estimations given above do not depend on the load-carrying scheme of the part. Similarly, the same zones of cranks are estimated.

4) The bracket body estimation.

It is mentioned above that the load-carrying work of the beam or truss bracket body elements are significantly different. Consequently, the estimations of these part elements are different.

a) The beam bracket body estimation.

The design estimation of the beam bracket body (Figure 16) rationally starts with defining the wall thickness. Assuming that the wall works in shear from the force P_y, its strength condition is:

$$\tau = \frac{Q_{cm\,i}}{H_i \cdot \delta_i} \leq [\tau]_p \qquad (10)$$

where $Q_{cm\,i}$ – the component of the shear force, which is taken by the wall in a i-cross section (Figure 18).

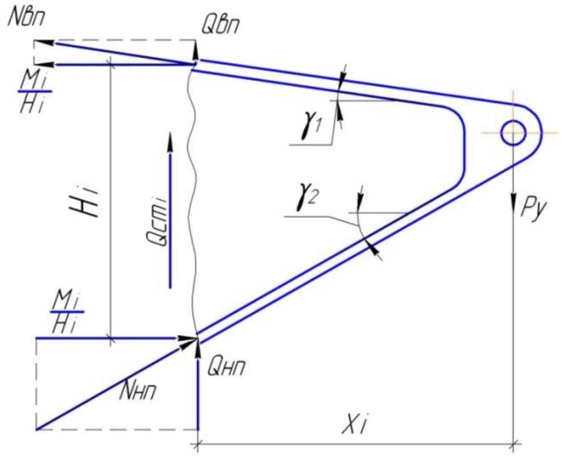


Figure 18 – The beam bracket

The bending moment of the bracket cross sections makes the normal stresses $N_{ВП}$ and $N_{НП}$ in belts. If belts are inclined (at angles γ_1 and γ_2) to the part axis the vertical components of these stresses partially balance the force P_y. From the equilibrium condition:

$$P_y = Q_{ВП} + Q_{НП} + Q_{cm\,i}.$$

Thus, the wall share in transferring the shear force is:

$$Q_{cm\,i} = P_y - Q_{ВП} - Q_{НП} \quad (11)$$

$$Q_{ВП} = \frac{M_i}{H_i} tg\gamma_1,\ Q_{НП} = \frac{M_i}{H_i} tg\gamma_2 \quad (12)$$

For the illustrated bracket the dangerous wall cross sections are Б-Б (the cross section with the minimum construction height) and В-В (the cross section with a hole).

For the cross section Б-Б from (10):

$$\delta_Б \geq \frac{Q_{cm\,Б}}{H_Б \cdot [\tau]_p}$$

As $M_Б = P_y X_Б$ and with taking into account (11) and(12):

$$\delta_Б \geq \frac{P_y\,[1-\frac{X_Б}{H_Б}(tg\gamma_1+tg\gamma_2)]}{H_Б[\tau]_p} \qquad (13)$$

Holes on the bracket walls (the cross section B-B) are made either for lightening the part in zones of the maximum heights, or for laying rods, pipes or electro binders through the bracket plane. At that, it is necessary to take into account the stress concentration at the hole edges:

$$\delta_B \geq \frac{P_y\,[1-\frac{X_B}{H_B}(tg\gamma_1+tg\gamma_2)]}{(h_B-h_{omв})[\tau]}k, \qquad (14)$$

where k – the coefficient of the stress concentration that is defined by reference books. To a first approximation it can be assumed:

$$k \approx 1+2\frac{b_{omв}}{h_{omв}}.$$

If there are several holes the required wall thickness should be defined for each cross section that has a hole.

In accordance with the manufacturing requirements the bracket wall thickness should be constant. The limits of the minimum wall thickness value of
$\delta_т$ [6, 7], which is attainable under the chosen method of manufacturing the part blank, also should be taken into account

The final value of the wall thickness is the maximum value of all calculated values:

$$\delta = max\{\delta_Б;\ \delta_В;\ \delta_Т\}.$$

Then, you should define the dimensions of belts (the cross section B-B): the belt width b_n and thickness δ_n. The shape and dimensions of the cross sections are defined, at least, for two outmost cross sections. The estimation is carried out in accordance with the cross section loading: there are usually bending with tension or compression.

The strength conditions for the upper and lower belts are similar:

$$\sigma_{ВПi} = \left(\frac{M_i}{W_i} \pm \frac{P_x}{F_i}\right)\frac{1}{cos\,\gamma_1} \leq [\sigma],$$

$$\sigma_{НПi} = \left(\frac{M_i}{W_i} \pm \frac{P_x}{F_i}\right)\frac{1}{\cos\gamma_2} \leq [\sigma], \tag{15}$$

where $\sigma_{ВПi}$, $\sigma_{НПi}$ – the normal stresses of the upper and lower belts;

M_i, W_i, F_i – the bending moment, the resisting bending moment, the area of the considered cross section.

The geometric characteristics of the cross sections (W_i, F_i) are fully defined by the dimensions of the cross section elements, in which the width b_n and the thickness δ_n of the upper and lower belts are unknown.

The consideration of two circumstances helps finding the rational values of these dimensions from one strength condition.

The first circumstance. In accordance with the manufacturing requirements the thicknesses of the belts (δ_n) should be constant along the whole length. Thus, finding the belt cross section area that requires the strength condition is provided by changing its width (b_n).

The second circumstance. The bracket belts can be loaded by compression stresses. The ratio of the belt width to its thickness should be not large for providing the flange stability. For the belt that is correctly designed:

$$\frac{b_n}{\delta_n} = 5 \dots 10. \qquad (16)$$

As the maximum belt stress and its maximum dimensions are in the bracket base cross section (the cross section Г-Г), it is rationally to start estimating this cross section.

Under the strength conditions (15) with taking into account recommendations (16) the belt thickness and its maximum width are calculated. The minimum width of the belts (the width of the belts is constant) is defined in the cross section Б-Б that has the minimum value of the bending moment.

The flanges of the compressed belts are necessary checked on the local stability.

Note that bodies of different levers and lever-type crank arms are generally similar to the beam bracket body. Thus, the estimation of such parts is carried out by this methodology.

б) The truss bracket body

The truss bracket body (Figure 14) consists of two belts, whose axes (lines that go through the gravity centres of the belt cross sections) should intersect at the point of the external load application.

The strength condition of the tensioned belt:

$$\sigma_{pacm} = \frac{N_{pacm}}{F_n} \leq [\sigma]_{pacm}. \qquad (17а)$$

The strength condition of the compressed belt

$$\sigma_{сж} = \frac{N_{сж}}{F_n} \leq [\sigma]_{сж}. \qquad (17б)$$

$$\sigma_{сж} \le \begin{Bmatrix} [\sigma]_{кро} \\ [\sigma]_{крм} \end{Bmatrix}.$$

Here $N_{раст}$, $N_{сж}$ – the tension and compression stresses of the belt;

$[\sigma]_{раст}$, $[\sigma]_{сж}$ – the acceptable stresses under the tension and the compression;

$[\sigma]_{кро}$, $[\sigma]_{крм}$ – the limit stresses of the overall and local stabilities.

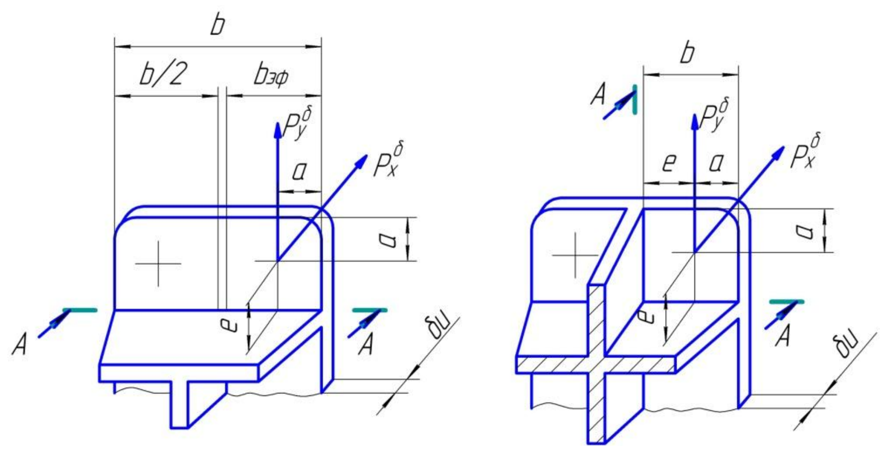
From (17a) and (17б) the required values of the belt cross section areas of F_n are defined under the compression and tension. The final value should be the maximum value of them.

The limit stresses of the overall and local stability losses are defined with the help of [5].

If the design model is adequate to the real construction the shape of the belt cross section can be arbitrary. In practice there are no full conformity, for example, there is no real swivel connection of the truss rods (the bracket belts) with the ear or the base. In process of the load-carrying work the local bending deformations, which are not considered in the estimation, occur in these zones. Thus, the belt cross section has the shape that is rational to work in the bending; it is usually I-shaped (Figure 14). Moreover, this shape meets the requirements of manufacturing the part and providing the belt stability.

5) The base estimation.

In most cases the base works as a plate with a seal on the bracket belt (Figure 19). Two variants of seals are available: single-face (Figure 19, the variant *a*) and corner seals (Figure 19, the variant *б*).



а *б*

Figure 19 – The plate with a seal on the bracket belt:

а – the single-face seal, *б* – the corner seal

The base width b is defined in accordance with the design circumstances:

– b can not be less than the width of the horizontal flange of the belt $b \geq b_n$;

– the restriction on the minimum distance between the bolt holes $t \geq 3d$ should be executed; d – the hole diameter;

– the minimum distance a from the hole axis to the base edge should be provided: $a \geq (1{,}5 \dots 2{,}0)d$;

– it is necessary to satisfy the manufacturing requirements that provide the tool access for tightening the bolt connection [9]. To a first approximation it can be assumed:

$e \geq 0{,}8\,S$ – for the single –face seal of the base

$e \geq 1{,}1\,S$ – for the corner seal of the base.

Here S – the bolt "flat-to-flat" dimension.

Thus, the base estimation comes down to defining the thickness $\delta_{осн}$.

The base works in collapse because of the stress ($P_y^б$) that shears the bolt.

$$\sigma = \frac{P_y^б}{d\,\delta_{см}} \leq \mu[\sigma]_p \qquad (18)$$

The coefficient $\mu=\begin{cases} 1{,}0 \ldots 1{,}3 - \text{separable joint} \\ 1{,}3 \ldots 1{,}5 - \text{permanent joint} \end{cases}.$

From (18) the base thickness is defined according to the strength condition for collapse $\delta_{см}$:

$$\delta_{см} \geq \frac{P_y^{б}}{d\mu[\sigma]_p}.$$

The base takes up bending because of the stress ($P_x^{б}$) that tensions the bolt. The dangerous cross section is A-A. Extension and compression stresses ($P_y^{б}$) also act in this cross section.

The strength condition for this cross section:

$$\sigma = \sigma_u + \sigma_{раст/сж} \leq [\sigma]_p. \quad (19)$$

Here σ_u – normal stress for base bending;

$\sigma_{раст/сж}$ – normal stress for base extension or compression.

The bending is constrained because of the contact between the base and the surface:

$$\sigma_{u} = K_{стес} \cdot \frac{M}{W};$$

$K_{стес}$ – coefficient which takes into account the constraint. Its value depends on the ratio of the bracket base rigidity to the surface rigidity. To the first approximation the value of $K_{стес}$ can be assumed $K_{стес}$ =0,5.

The finite element analysis of this zone of similar models can give the more accurate value of $K_{стес.}$

$M = P_x^{б} l$ – the bending moment of the cross section A-A.

W – the resisting bending moment of the cross section A-A.

For the cross section A-A that has a rectangular shape:

$$W = \frac{b_{расч}\delta_u^2}{6},$$

δ_u – the base thickness according to the strength condition of bending;

$b_{расч}$ – the «calculated» base width:

$b_{расч} = min\left\{\frac{b}{2}; b_{эф}\right\}$ – for the single-face seal of the base (the variant a);

$b_{расч} = min\{b; b_{эф}\}$ – for the corner seal of the base (the variant б);

$b_{эф}$ – the width of the base segment that effectively works in bending.

To a first approximation we can assume:

$b_{эф} = S + 3{,}5e$ – for the single-face seal of the base, where S – the bolt "flat-to-flat" dimension. ;

$b_{эф} = 2a + 0{,}5\pi e$ – for the corner seal of the base.

Thus, the strength condition (19) can be written in the following form:

$$3\frac{P_x^б e}{b_{расч}\delta_u^2} + \frac{P_y^б}{\delta_u b_{расч}} \leq [\sigma]_p \tag{20}$$

From (20) the required base thickness value of δ_u of the cross section A-A is defined.

The final base thickness is the maximum value of two calculated values:

$$\delta_{осн} = max\{\delta_{см}; \delta_u\}.$$

In case, when there is definitely no a load that acts perpendicularly to the bracket plane on, the variant of fixing the part between two trailing edges of ribs (the Figure 20). Such brackets are made in the form of a plate of the constant thickness. The fixing parts work in shear in two planes, the shear components are stresses of the external forces P_x, P_y and moments of the off-centre application of the external forces (the moments of the forces P_x and P_y according to the gravity centre of the fixing parts – т.C). The calculations of the resultant stress, which shears a bolt (a rivet), and the maximum loaded bolt are given in [5].

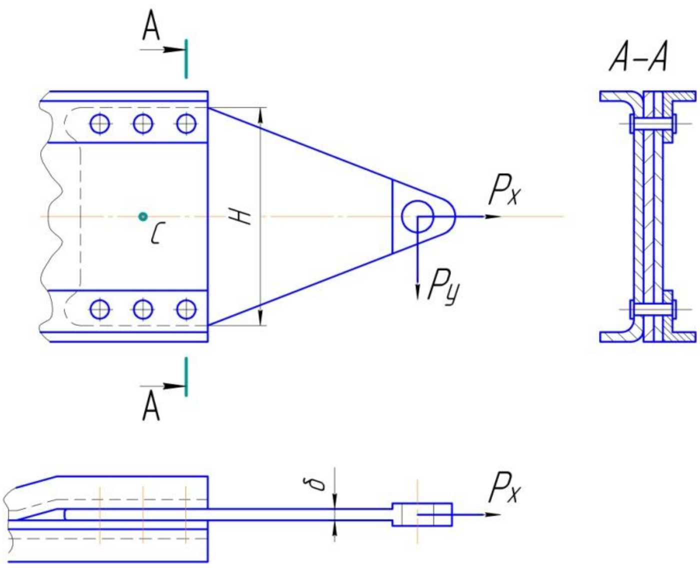


Figure 20 – Fixing the part between two trailing edges of ribs

The analysis of the load-carrying work of this type of fixing the bracket allows making the following recommendations:

а) it is rational to place rivets at the maximum distance from their own centre of gravity (т.C), using the whole construction height of the support (it decreases the fixing stress from the off-centre application of the external force.

б) The fixing elements should be compactly placed in the direction of the bracket axis (with the minimum distance between the fixing elements), i.e. it decreases an arm of the force P_y and the moment value of the the off-centre application of the external force;

в) It is inappropriate to place the bolts (rivets) on the bracket axis. The fixing element, which is in front of the elastic centre, is greatly overloaded, and the fixing element, which is behind the elastic centre, ineffectively works.

The dangerous cross section of the bracket is A-A, which is weakened by bolt holes (rivet holes), and also it takes the total load. Generally, a cross section works in bending with tension-compression, which causes the normal stresses in this cross section. The normal stresses are σ_u and $\sigma_{раст/сж}$, and the shear stresses, that are caused by the force P_y, are τ. The cross section dimensions are defined from the condition of the combined action of these load-carrying factors:

$$\sigma = \sqrt{\left(\sigma_u + \sigma_{\text{раст/сж}}\right)^2 + 4\tau^2} \leq [\sigma]_p. \tag{21}$$

Taking into account the rectangular shape of the cross section A-A and its state that is weakened by holes, we obtaine

$$\sqrt{\left[\frac{6M}{(H-nd)(\delta')^2} + \frac{P_x}{(H-nd)\delta'}\right]^2 + 4\left[\frac{P_y}{(H-nd)\delta'}\right]^2} \leq [\sigma]_p, \tag{22}$$

where M – the bending moment of the cross section A-A;

d, n – the diameter and number of holes that are in the cross section A-A.

Keeping in mind the necessity of using the maximum construction height of the bracket (H), from (22) the required thickness of the part sheet *(δ')* is defined.

The sheet thickness should be defined for providing the part strength to collapse:

$$\sigma = \frac{P_{cp}^{max}}{d\delta''} \leq 1{,}3[\sigma]_p,$$

From where

$$\delta'' \geq \frac{\mathrm{P}_{\text{cp}}^{max}}{d1{,}3[\sigma]_p}.$$

Here P_{cp}^{max} – the shear stress of the maximum loaded bolt (rivet).

The maximum value of two calculated values is taken for the final value of the part sheet thickness:

$$\delta = max\{\delta^{'}; \delta^{''}\}.$$

When you execute this work, the description of each estimation should comprise a sketch and (or) a design schemes of the calculating part element or cross section; also it should comprise the task definition, the initial data of estimations, design conditions, the estimations and the estimation conclusion.

The summary of the estimation results is a summary table of strength excess coefficients of all calculated cross sections. The separate dimensions of the part are defined not by the strength considerations but by the design considerations (for example, the conditions of placing the fixing elements and providing the tool access) The strength excess coefficients of these dimensions can have large values.

9 THE MODIFICATION OF THE PART CROSS SECTION WITH TAKING INTO ACCOUNT THE TECHNOLOGICAL FACTORS AND RESTRICTIONS

The method of manufacturing parts (hot stamping, casting, welding, machining) imposes its restrictions on the part shape and dimensions and its separate elements. The corresponding requirements are given in the recommendations of manufacturability [4] for each method.

When you save the calculated cross section areas of parts that are manufactured by hot stamping [7], you should choose the plane orientation of parting of a die, the sheet thickness and its inclination angle, the area of lightening holes, which are punched during the stamping, the rib thickness and height and the distance between the ribs. For the parts, which are manufactured by casting [6], you should choose the casting method, the part and its elements shape, which provides the evenness of cooling the cast, the form parting surface, the part draft angles, the minimum wall thicknesses, the thicknesses of the ribs and the distance between them, the radius of conjugation and fillet and the limit deviations of the dimensions.

Note that the choice of the part elements dimensions should be made with taking into account the subsequent machining of conjugated surfaces and, sometimes, the lightening or the mass fitting. After choosing the part dimensions you should assign antirust covering of the part using the recommendations in [15].

10 EXECUTING THE PART DRAWING

The part drawing should be made in accordance with the requirements of GOST 2.109-70. The part drawing should contain all information that is necessary for manufacturing and controlling the part, as well as for developing drawings of technological rigging elements.

The part drawing is done on the paper of standard size (A3 is recommended).

It is usually enough to plot two main views and two - three cross section views, which illustrate the part shape, on the dawing.

The challenge is to show the complete conception of the part using the smallest number of lines.

Then, all necessary dimensions in its limit deviations are plotted on the drawing. Plotting the dimensions should be made from bases of the machining operations. These bases are usually set up by the design bases.

The necessary surface roughness should be plotted on part places that are machined. The surface finish class and its accuracy should be tied with each other. The technical requirements of the drawing should comprise the heat treatment method, the covering system, control requirements, the mass fitting method and the marking method [22].

In the title block of the drawing it is necessary to define the material as it is supplied, the part mass. The drawing designation is made in accordance with the normal 57A0.

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THE APPENDIX 1

Table 1.1 – The swivel bearings: radial, spherical, double-row

The bearing type	Dimensions					The number of balls	The acceptable load, daN			The failing radial load under swinging Рразр, daN
	The bearing				The ball		Static Qст	Radial under 100 000 cycles of swinging Рдоп	Radial under 25 000 cycles of swinging Рдоп	
	d	*D*	*b*	*r*	$d_ш$					
1005	5	19	6	0,5	3,175	16	50	220	320	1700
1006	6	19	6	0,5	3,175	16	50	220	320	1700
1007	7	22	7	0,5	3,175	20	70	280	400	2000
1008	8	22	7	0,5	3,175	20	70	280	400	2000
1009	9	26	8	1	3,969	18	90	395	560	2700
1200	10	30	9	1	4,763	18	140	570	810	3700
1300	10	35	11	1	5,556	18	180	910	1300	4700
1201	12	32	10	1	4,763	20	150	630	900	3800
1301	12	37	12	1,5	6,35	18	240	1200	1700	5800
1202	15	35	11	1	5,556	20	200	860	1230	4900
1302	15	42	13	1,5	6,35	20	270	1330	1890	6000
1203	17	40	12	1,5	5,556	24	250	1030	1480	5500
1303	17	47	14	1,5	7,144	22	370	1850	2640	7800
1204	20	47	14	1,5	6,35	24	320	1350	1930	6300
1304	20	52	15	2	7,144	24	410	2020	2880	8000
1205	25	52	15	1,5	7,144	24	410	1710	2450	7300
1305	25	62	17	2	8,731	24	610	3020	4300	10000
1206	30	62	16	1,5	7,938	28	590	2470	3530	9700
1306	30	72	19	2	9,525	26	830	3900	5500	10600
1207	35	72	17	2	7,938	32	680	2820	4030	10000
1307	35	80	21	2,5	10,319	28	1000	4900	1000	11800
1208	40	80	18	2	8,731	34	780	3630	5180	11600
1308	40	90	23	2,5	11,113	30	1300	6100	8600	14700
1209	45	85	19	2	9,525	32	980	4060	5800	11600
1210	50	90	20	2	9,525	36	1100	4570	6530	13000
1211	55	100	21	2,5	10,319	38	1360	5660	8090	16000
1212	60	110	22	2,5	11,113	38	1580	6570	9380	18000

Table 1.2 The swivel bearings: radial, spherical, double–row with two shields without a distance ring

The bearing type	Dimensions						The number of balls	The acceptable load, daN		The failing radial load under swinging Rразр, daN
	The bearing					The ball		Radial under 100 000 cycles of swinging Rдоп	Radial under 25 000 cycles of swinging Rдоп	
	d	*D*	*b*	b_1	*r*	$d_ш$				
The swivel bearings: radial, spherical, double –row with two shields without a distance ring										
971067	7	24	12	18	1	3,175	30	450	700	2400
971800	10	37	16	20	1	5,159	28	1200	1500	4500
The swivel bearings: radial, spherical, double –row										
961066	6	22	7	11	0,5	3,175	20	280	400	2000
The swivel bearings: radial, spherical, single –row with two shields without a distance ring										
981065	5	20	7	8	0,5	3,175	12	240	300	1200
981067	7	24	9	12	0,8	3,969	12	380	460	1800
981028	8	24	12	16	0,5	3,969	12	380	460	1800
981028	8	30	10	14	0,5	4,763	13	590	740	2900
981700	10	37	12	16	0,5	5,556	13	640	800	3200
981701	12	42	13	17	0,8	6,35	13	850	1050	4200
981702	15	52	15	20	1	8,731	12	1450	1800	7300
981704	20	52	15	20	1	7,144	16	1300	1600	6500
981705	25	62	17	22	1	8,731	15	1800	2200	9200

Table 1.3 – The acceptable load of the swivel bearings

The identification marks of the bearings		Dimensions, mm						The acceptable load, daN	
for movable joints	For fixed joints	*d*	*D*	*b*	b_1	d_1	*r*	for Ш and ШС	for ШМ
Ш5; ШС5	ШМ5	5	14	4	6	10	0,5	1000	2000
Ш6; ШС6	ШМ6	6	14	4	6	10	0,5	1000	2000
Ш7; ШС7	ШМ7	7	17	5	8	13	0,5	1625	3250
Ш8; ШС8	ШМ8	8	17	5	8	13	0,5	1625	3250
Ш9; ШС9	ШМ9	9	20	6	9	16	0,5	2400	4800
Ш10; ШС10	ШМ10	10	20	6	9	16	0,5	2400	4800
Ш12; ШС12	ШМ12	12	22	7	10	18	1	3150	6300
Ш15; ШС15	ШМ15	15	28	8	12	23	1	4600	9200
Ш17; ШС17	ШМ17	17	32	10	14	26	1	6500	13000
Ш20; ШС20	ШМ20	20	35	12	16	29	1	8700	17400
Ш25; ШС25	ШМ25	25	42	16	20	35	1	14000	28000
Ш30; ШС30	ШМ30	30	47	18	22	40	1	18000	36000
Ш35; ШС35	ШМ35	35	55	21	26	47	1,5	24675	49350
Ш40; ШС40	ШМ40	40	62	22	28	53	1,5	29150	58300
Ш45; ШС45	ШМ45	45	70	25	32	60	2	37500	75000
- ШС50	ШМ50	50	75	28	35	66	2	46200	92400
- ШС55	-	55	85	32	40	74	2	59200	-
- -	ШМ60	60	90	34	44	80	2	-	136000
- ШС100	-	100	125	25	30	114	1,5	71250	-
- ШС101	-	110	150	35	40	132	2	115500	-
2Ш10; 2ШС10	2ШМ10	10	30	10	14	22	1	5500	11000
2Ш12; 12ШС12	2ШМ12	12	32	12	16	24	1	7200	14400
2Ш15; 12ШС15	2ШМ15	15	35	14	18	27	1	9450	18900
2Ш17; 12ШС17	2ШМ17	17	40	14	21	31	1	10850	21700
- -	2ШМ20	20	47	15	26	35	1	-	26250
- -	2ШМ25	25	52	15	28	40	1,5	-	30000
- -	9ШМ35	35	55	15	22	46	1	-	34500
- -	2ШМ45	45	85	23	30	69	2	-	79350

THE APPENDIX 2

DESIGN FORMULAS FOR CALCULATING THE LOAD-CARRYING FACTOR OF CONSTRUCTION ELEMENTS UNDER DIFFERENT STRESSED STATES

The load–carrying factor is a complex characteristic of the load-carrying work of the construction; it takes into account the value of internal stresses of the construction elements and the extension of these stresses action. Generally, the load–carrying factor C_G is calculated as:

$$G = \int_V \sigma_{прив} dV,$$

where $\sigma_{прив}$ – the reduced stress - the stress of the single-axis stress state that is equal to the stresses, which act in infinitesimal construction volume dV, by the specific potential energy;

The reduced stress is related to components of the actual stress state by the following relations:

— The single-axis stress state (tension or compression):

$$\sigma_{np.} = |\sigma|;$$

— Two-axes flat) stress state with components σ_x, σ_y, τ_{xy}:

$$\sigma_{\text{пр}} = \sqrt{\sigma_x^2 + \sigma_y^2 - 2\mu\sigma_x\sigma_y + 2(l+\mu)\tau_{xy}^2},$$

Or with the main stresses σ_I, σ_{II}:

$$\sigma_{np} = \sqrt{\sigma_I^2 + \sigma_{II}^2 - 2\mu\sigma_I\sigma_{II}};$$

hereinafter μ - the Poisson's ratio.

— Three-axis (volume) stress state (the components σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, τ_{zx}):

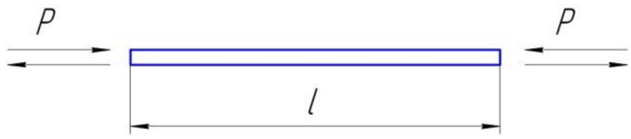
$$\sigma_{np} == \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - 2\mu\left(\sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x\right) + 2(1+\mu)\left(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right)},$$

Or with the main stresses σ_I, σ_{II}, σ_{III}

$$\sigma_{np} = \sqrt{\sigma_I^2 + \sigma_{II}^2 + \sigma_{III}^2 - 2\mu(\sigma_I\sigma_{II} + \sigma_{II}\sigma_{III} + \sigma_{III}\sigma_{Ix})}.$$

1. Elements are in single-axis stress state.

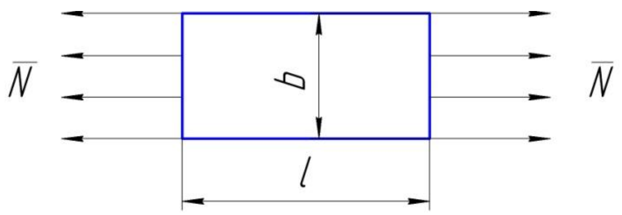
1.1 The rod of length l is loaded by$\pm P$



1.2 Figure П 2.1 – The rod of length l is loaded by$\pm P$

$$G = |P|l.$$

1.3 The plate of the constant thickness δ with planform dimensions l and b in the single-axis field of line loads $\pm\ \bar{N}=\pm\sigma\delta$



1.4 Figure П 2.2 – The plate of the constant thickness δ with planform dimensions l and b in the single-axis field of line loads $\pm\ \bar{N}=\pm\sigma\delta$

$$G = \overline{N}bl = Pl,$$

(P – the external force: $P= \bar{N}b$).

1.5 The truss that consists of n-rods with numbers i, the rod length l_i and the rod stresses $/N_i/$:

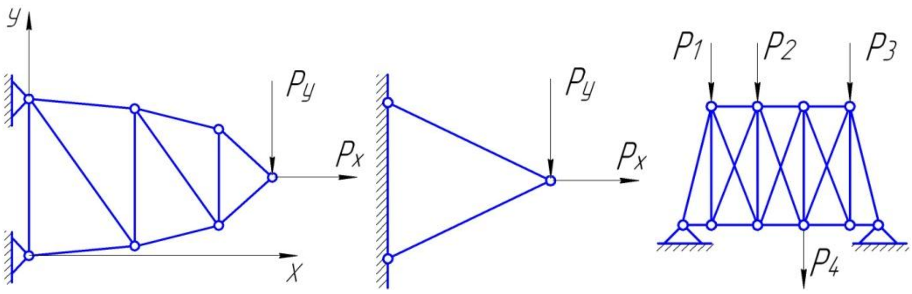
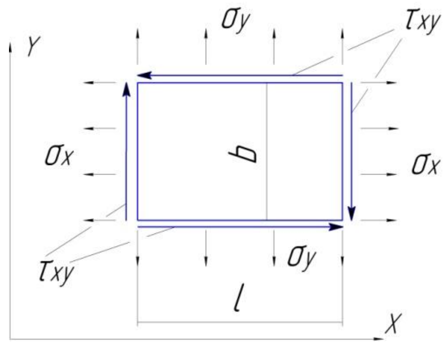


Figure П 2.3 – The truss that consists of n-rods with numbers i, the rod length l_i and the rod stresses $/N_i/$:

$$G = \sum_{i=1}^{i=n} |N_i| l_i.$$

2. Elements are in the two-axes stress state.

2.1 The plate of the constant thickness δ with planform dimensions l and b in the flat stress state with stress components σ_x, σ_y, τ_{xy}:



2.2 Figure П 2.4 – The plate of the constant thickness δ with planform dimensions l and b in the flat stress state with stress components σ_x, σ_y, τ_{xy}:

$$G = \sigma_{прив} V = lb\delta\sqrt{\sigma_x^2 + \sigma_y^2 - 2\mu\sigma_x\sigma_y + 2(1+\mu)\tau_{xy}^2} = lbR_{прив}$$

($R_{прив}$ – the reduced stress flow $R_{прив}=\delta\sigma_{прив}$).

2.3 The plate of the same dimensions under conditions of pure shear ($\sigma_x=\sigma_y=0,\ \tau_{xy}\neq 0,\ |\sigma_I|=|\sigma_{II}|=|\tau_{xy}|$)

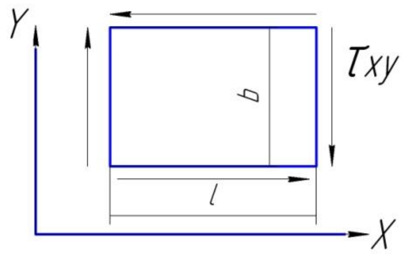


Figure П 2.5 – The plate of the constant thickness δ with platform dimensions l and b under conditions of pure shear

$$G = V\sigma_{прив} = lb\delta\sqrt{\sigma_I^2 + \sigma_{II}^2 - 2\mu\sigma_I\sigma_{II}} = lb\delta\sqrt{2(1+\mu)\tau_{xy}^2} = \sqrt{2{,}6}\tau_{xy}\, lb\delta$$
$$= \sqrt{2{,}6}Ql$$

($Q=\tau_{xy}\delta b$ – the shear force, which acts in the plate cross section).

2.4 The beam is in the form of ideal or real I-beam under the cross bend: the combination of rods, which are under the single-axis tension or compression, and walls, which are under the pure shear:

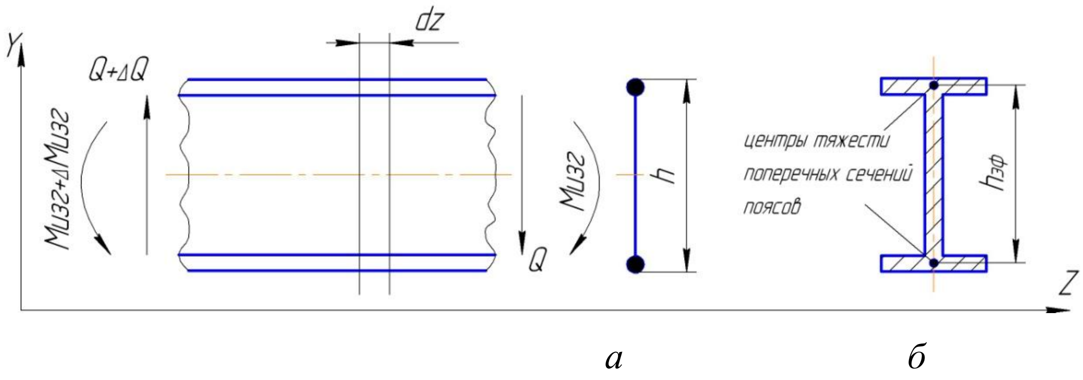


Figure П 2.6 – The beam is in the form of ideal I-beam(a) and the real I-beam ($б$)

For the variant a:

$$dG = 2\left|\frac{M_{изг}(z)}{h}\right| dz + \sqrt{2{,}6}Qdz.$$

For the variant б:

$$h_{эф} = \aleph h;\ \ \aleph = \frac{h_{эф}}{\eta};$$

$$dG = 2\left|\frac{M_{изг}(z)}{h_{эф}}\right| dz + \sqrt{2{,}6}Q(z)dz = 2\left|\frac{M_{изг}(z)}{\aleph h}\right| dz + \sqrt{2{,}6}Q(z)dz.$$

$$G = 2\int_{l} \left|\frac{M_{изг}(z)}{h(h_{эф})}\right| dz + \sqrt{2{,}6}\int_{l} Q(z)dz.$$

2.5 There is a thin-walled cylindrical shell of the thickness δ (a thin-walled closed contour with the contour area Ω and the perimeter Π), which is loaded by the bending moment $M_{кр}$ at the segment of the length l.

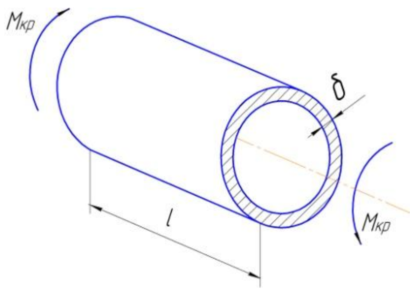


Figure П 2.7 – The thin-walled cylindrical shell of the thickness thin-walled cylindrical shell of the thickness δ, which is loaded by the bending moment $M_{кр}$ at the segment of the length l.

The shell material is under pure shear, the shear stresses of the shell cross section (in the closed contour) are:

$$\tau = \frac{M_{кр}}{2\Omega\delta}.$$

$$G = V\sigma_{прив} = \Pi\delta l \frac{M_{кр}}{2\Omega\delta}\sqrt{2{,}6} = \frac{\sqrt{2{,}6}}{2} M_{кр} l \frac{\Pi}{\Omega}.$$

For circular cylinder of the radius r:

$$G = \sqrt{2{,}6}\frac{M_{кр}}{r} l.$$

2.6 There is a segment of the thin-walled circular cylindrical shell of the radius r, the length l and the thicknessδ, which is loaded by the excessive internal pressure

$p_{изб}$ (the segment of a pressurized fuselage at the enough distance from от pressurized frames).

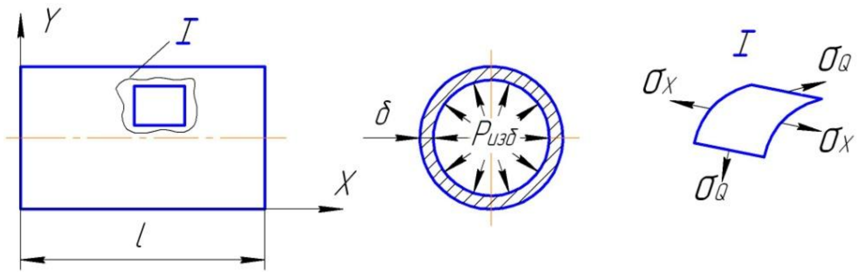


Figure П 2.8 – The segment of the thin-walled circular cylindrical shell of the radius r, the length l and the thickness δ, which is loaded by the excessive internal pressure $p_{изб}$

The shell material is under the two-axes stress state. In cylindrical coordinates the components of the tension stresses are calculated as:

$$\sigma_x = \frac{p_{изб} r}{2\delta}; \qquad \sigma_o = \frac{p_{изб} r}{\delta}; \qquad \tau_{xo} = 0.$$

Obviously, that $\sigma_{прив} \approx \sigma_o$, so

$$G = \sigma_o 2\pi r \delta l = 2\pi r^2 l p_{изб}.$$

THE APPENDIX 3

DESIGN FORMULAS FOR CALCULATING THE LOAD-CARRYING FACTOR OF THE BEAM BRACKET

There are the design formulas for calculating the load-carrying factor of the bracket in cases, when the axes of the rods-belts of the beam bracket intersect in front of the ear centre (the variant *б* in the Figure 10) or behind the ear centre (the variant *в* in the Figure 10).

<u>The variant *б*.</u>

The initial expression for calculating the load-carrying factor of the bracket segment, which does not have the ear of the diameter *D*:

$$G^{б} = \frac{2P}{sin\, 2\alpha_{б}} \int_{D/2}^{L} \frac{x}{x - a_1} dx + \sqrt{2{,}6}P \int_{D/2}^{L} \frac{a_1}{x - a_1} dx.$$

Here the first summand shows the load-carrying factor of belts $G_n^{б}$, the first summand shows the load-carrying factor of the bracket wall $G_{cm}^{б}$. Let's integrate each summand separately:

$$G_n^{б} = \frac{2P}{sin\, 2\alpha_{б}} \int_{\frac{D}{2}}^{L} \frac{x}{x - a_1} dx = \frac{2P}{sin\, 2\alpha_{б}} \int_{\frac{D}{2}}^{L} \frac{x - a_1 + a_1}{x - a_1} dx$$

$$= \frac{2P}{sin\, 2\alpha_{б}} \int_{\frac{D}{2}}^{L} \left(1 + \frac{a_1}{x - a_1}\right) dx =$$

$$= \frac{2P}{sin\, 2\alpha_{б}} \left\{L - \frac{D}{2} + a_1 \left[ln(L - a_1) - ln(\frac{D}{2} - a_1)\right]\right\} =$$

$$= \frac{2P}{sin\, 2\alpha_{б}} (L - \frac{D}{2} + a_1\, ln \frac{L - a_1}{\frac{D}{2} - a_1});$$

so,

$$G_n^{б} = \frac{2P}{sin\,2\alpha_б}(L - \frac{D}{2} + a_1\, ln\frac{L - a_1}{\frac{D}{2} - a_1}).$$

$$G_{cm}^{б} = \sqrt{2{,}6}P\int_{D/2}^{L}\frac{a_1}{x - a_1}dx = \sqrt{2{,}6}Pa_1\, ln\frac{L - a_1}{\frac{D}{2} - a_1}.$$

The final expression of the load-carrying factor of the bracket of the variant *б* is:

$$G^{в} = \frac{2P}{\sin 2\alpha_б}(L - \frac{D}{2} + a_1 \ln\frac{L - a_1}{\frac{D}{2} - a_1}) + \sqrt{2{,}6}Pa_1 \ln\frac{L - a_1}{\frac{D}{2} - a_1}.$$

<u>The variant *в*.</u>

The initial expression for calculating the load-carrying factor of the same bracket segment:

$$G^{в} = \frac{2P}{\sin 2\alpha_в}\int_{D/2}^{L}\frac{x}{x + a_2}dx + \sqrt{2{,}6}P\int_{D/2}^{L}\frac{a_2}{x + a_2}dx.$$

Similarly to the variant *б*, we obtain:

$$G_n^{в} = \frac{2P}{\sin 2\alpha_в}\int_{D/2}^{L}\frac{x + a_2 - a_2}{x + a_2}dx = \frac{2P}{\sin 2\alpha_в}\int_{D/2}^{L}\left(1 - \frac{a_2}{x + a_2}\right)dx =$$
$$= \frac{2P}{\sin 2\alpha_в}\left\{L - \frac{D}{2} - a_2\left[\ln(L + a_2) - \ln(\frac{D}{2} + a_2)\right]\right\} =$$
$$= \frac{2P}{\sin 2\alpha_в}\left(L - \frac{D}{2} - a_2 \ln\frac{L + a_2}{\frac{D}{2} + a_2}\right);$$

so,

$$G_n^{\text{в}} = \frac{2P}{\sin 2\alpha_{\text{в}}}\left(L - \frac{D}{2} - a_2 \ln \frac{L + a_2}{\frac{D}{2} + a_2}\right).$$

$$G_{cm}^{в} = \sqrt{2{,}6}P \int_{D/2}^{L} \frac{a_2}{x + a_2} = \sqrt{2{,}6}Pa_2 \ln \frac{L + a_2}{\frac{D}{2} + a_2}.$$

The final expression of the load-carrying factor of the bracket of the variant *в* is:

$$G^{в} = \frac{2P}{\sin 2\alpha_{\text{в}}}\left(L - \frac{D}{2} - a_2 \ln \frac{L + a_2}{\frac{D}{2} + a_2}\right) + \sqrt{2{,}6}Pa_2 \ln \frac{L + a_2}{\frac{D}{2} + a_2}.$$

THE APPENDIX 4

Table 4.1 –Examples of materials, which are applied for manufacturing the parts

The material grade	σ_B, MPa	The supply condition	The general application
30ХГСА	1100 – 1300	Поковки	Important joints, brackets, fittings
35ХГСЛ	1000	Отливки	Landing gear parts, struts and etc.
АЛ9	210	Литье	Midloaded parts
АЛ19	340	Литье	Loaded parts
В95Т1	540	Прутки	Machined parts
АК4-1	370	Прутки	Forged parts that work under the temperature 200^{o}C
АК-6	370	Поковки	Brackets and related parts
ВТ1	360 – 550	Штамповка	Frame parts
ВТ22	1300	Поковка	Accurate stamped parts
БрАЖМц10-3-1,5	600	Прутки	Parts with c friction surfaces