Mounting clamps of building constructions

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Abstract. The article considers an innovative mounting clamp, which allows creating fundamentally new dismountable building constructions, engineering structures and outfits. While considering different methods of structural morphology, the article geometrically interprets the space-planning and technology requirements set for the framework of the designed building surface. The whole complex of the research, development and engineering works was performed, and it confirmed the proposed performance characteristics of the innovative mounting clamp – ball clamp. In the course of works a number of analogs of mounting clamps used in the constructions’ assembly were analyzed, their disadvantages were determined, and an innovative mounting clamp – ball clamp – was engineered. The advantages of the ball clamp as compared to its analogs were confirmed by the computations and tests performed at the laboratory of SUSU (NRU). Using the 3D computer modeling allowed creating a new design of the ball clamp manufactured by the cold-forming method. The 3D modeling provided a possibility to develop the design documentation and make preparations for series production of the ball clamp, as well as improve the capacity of its manufacture and considerably reduce the prime cost.

1. Introduction
Free-standing and non-self-supporting types of scaffolding are widely used in construction. Standard mounting clamps are used for the assembly of non-self-supporting scaffolding, and as a result this type of scaffolding does not feature a sufficient spatial stability margin. To improve the stability and reliability, it is required to fix such structures to a building under construction with anchor bolts. In order to ensure the relevant stability of temporary building metal constructions, so that fixing them to stationary facilities is no longer needed, fundamentally new mounting clamps are required. The market of building metal constructions is highly competitive. For instance, there are around 750 manufacturers of metal constructions in the Russian Federation. The Russian market of scaffolding suppliers comprises 101 companies [1]. To make Russian products highly competitive on the global market, innovative design solutions are required, which would meet all the criteria of patentability.

2. Comparative analysis of mounting clamps
At present, standard clamps are mostly offered in the Russian market of mounting clamps used for the assembly of building structures and scaffolding.

This article considers the following as standard mounting clamps:
• blind clamp; it consists of three pin-connected parts and fixes two mutually perpendicular pipes of 48 millimeters in diameter with two M14 bolts (Figure 1);
• FORCON coupling clamp; consists of three separate parts and fixes two mutually perpendicular pipes of 48 millimeters in diameter with four M14 bolts (Figure 2);
• Timbering clamp, engineered by Krepej company from the city of Ufa; it consists of two separate parts and fixes two mutually perpendicular pipes of 48 millimeters in diameter with two M14 bolts (Figure 3).

As a result of the comparative analysis of the design and technology parameters of different mounting clamps, the authors have come to the conclusions following below.

1. The designs of the blind clamp and of the FORCON coupling clamp are clumsy and complex.

2. The blind clamp, the Timbering clamp and the FORCON coupling clamp connect two bars of 48 millimeters in diameter with two or four M14 bolts. Therefore, to connect three bars, two clamps and four or eight M14 bolts will be required.

3. Connecting of three pipes with two staggered clamps will not ensure relevant stability of the whole construction.

![Figure 1. Blind clamp.](image)

![Figure 2. FORCON coupling clamp.](image)

![Figure 3. Timbering clamp by Krepej company, Ufa.](image)

Such designs are used to produce only the non-self-supporting type of scaffolding.

3. Formulation of the problem

Based on the results of analyzing the existing designs of mounting clamps, the work objective has been formulated: to improve the spatial stability of constructions through the use of an innovative mounting clamp. The mounting clamp has been developed based on the ideas and methods of descriptive geometry [2-8]. The position of a point in space is fully defined by the three degrees of freedom, therefore, a mounting clamp should fix the position of the three bars passing through this point. The mounting clamp should be dismountable, easy to manufacture, and be characterized with high (as compared to the analogs) spatial stability and reliability.

4. Stage one. Research and development works

Several variants of the ball clamp design have been suggested. A utility model certificate has been obtained for the “device for detachable connection, which simultaneously connects three long-length elements” [9], (Figure 4).

The ball clamp consists of two identical hemispherical cups (Figure 5) with symmetrically located cutouts for pipes or bars of 12 to 80 millimeters in diameter. The hemispherical cups fix the bars in a mutually perpendicular position with one bolt or pin.

The ball clamp is unique for its perfect combination of a spherical shape, symmetry, broad contacting area, big clamping force, and the self-fixation effect. The self-fixation effect occurs in case of the operational load on the connected bearing pipes.
The scientific novelty of the suggested solutions is in the development of the innovative mounting clamp – ball clamp, the design and technology advantages of which allow to create fundamentally new dismountable building constructions, engineering structures and process equipment.

The ball clamp is intended for detachable connection of tubular constructions being part of multi-purpose dismountable spatial bearing constructions with reliable inner stability and long operation life (Figure 6).

Using the ball clamp when creating dismountable constructions allows to reduce the specific consumption of metal for such constructions, as well as their assembly expenses, what makes the product considerably cheaper. The mockup test samples of the ball clamp have been manufactured with multi-purpose lathe and milling machines under single-piece production technology, without using special process equipment or contrivances.

5.  Stage two. Engineering works
The complete set of the engineering works has been performed in compliance with the regulatory documentation of the Russian Federation.

The following design documentation has been developed as a result of the carried out engineering works:

- specifications;
- drawings and technical documentation;
- operation manual;
- commissioning tests program;
- periodic tests program; and
- passport.

Experimental and computational studies have been performed by the specialists of SUSU (NRU). The scientific report has been prepared on the results of the mechanical tests and computations of the strain-stress state of the ball clamp using two methods of testing:

- compression (shear) test; and
• tension (deflection) test.

Multi-purpose МЗТВОМ5882 testing machine has been used to perform the trials. Based on the testing results the conclusion has been made on high operation capacity of the ball clamp.

The strength parameters of the ball clamp have been confirmed by the computations and periodic tests carried out by OOO IK TOR in the SUSU (NRU) laboratory. The design documentation has been registered in the Federal State Institution Chelyabinsk Center for Standardization, Metrology and Certification under No.074/010106 as of 19.02.2004. The work pieces of the ball clamp cups of spherical shape have been manufactured by milling. Certificate of Conformance No. ПОККРУ. ЧС08. H00009 (with Mosstroisertififikatsiya) has been obtained based on the results of work, as well as the Patent for Invention for the “device for detachable connection of long-length elements” [10].

6. Developing the design and outfit to manufacture the ball clamp using the cold-forming method and computer modelling

The manufacture of the ball clamp as small-series production using milling machines has its disadvantages (labor intensity, low production capacity, big amounts of metal waste, high prime cost), what impedes the successful promotion of the product on the market of innovative mounting clamps.

Further improvement of the design and manufacturability of the ball clamp has been conducted using computer graphics [11]. The constructional kinematic method has been used as the main method, which allows to picture the surface and show the points and lines pertaining to it. The surface framework has been produced from the multiple algebraic curved lines. Straight lines, second-order curves, and second-order focal surfaces are favored. The straight lines, tangent to the second-order surface, form a three-parameter locus of lines (line complex). To produce a one-parameter ruled surface from the three-parameter line complex, additional curvilinear guiding lines are used, which allow to control the shape of the surface. The constructional kinematic method allows to design smooth outer shells, resting on an arbitrary spatial contour [12-20]. An example of building smooth composite surfaces passing through the given contour and including the given part of the second-order focal surface is shown in Figure 7.

Figure 7. Ball clamp cup.

The ball clamp has been engineered using SOLIDWORKS graphic editor. Reasonable combination of the computer graphic tools and the theoretical methods of descriptive geometry has allowed to produce the surfaces complying with the preset geometric conditions (Figure 8). The digital model of the ball clamp has been recorded as an STL file to produce mockup samples using Picasso PRO250 3D printer (Figure 9).

Figure 8. Ball clamp assembled with pipes as created using SOLIDWORKS program.  
Figure 9. 3D-printed ball clamp.
The technology of series production of the ball clamp cups from the parent sheet using the cold-forming method has been developed. Computer modelling of the ball clamp has allowed to reduce its weight and increase the area of the ball clamp cup contacting with the connected pipes. The increase in the contacting area between the cup and the pipes has improved the clamp’s efficiency and reliability (Figure 10).

Figure 10. Ball clamp with the pipes of 48 millimeters in diameter.

The technical documentation both on the ball clamp and the outfit (preliminary and final drawing die) has been modified. The strain-stress state of the blank part in the process of deformation has been calculated. The blank part deformation kinetics has been analyzed using the finite elements method in the LS-DYNA package (Figure 11). Based on the results of the computation, the blank part tempering before and after the forming has been recommended, and the maximum thickness of the parent sheet has been determined [21].

The organization of the series production using the cold-forming method has allowed to reduce the prime cost by 40% and to simultaneously increase the labor efficiency by more than three times. The ball clamp’s digital model provides a possibility to perform the finishing processing of the cups’ surfaces, where the connected pipes will run, using programmable high-capacity milling machines (WINNER PRO 4i (1325, 2030)), what considerably improves the ball clamp’s competitive attractiveness in the Russian market of mounting clamps.

7. Conclusions
1. As a result of the performed research, development and engineering works, the design documentation for the innovative mounting clamp (ball clamp) has been developed. Strength calculations and prototype testing have been performed.
2. The design documentation for the ball clamp has been registered in the FSU Chelyabinsk Center for Standardization, Metrology and Certification. Certificates of Conformance for all the standard sizes of the ball clamp have been obtained.
3. Series production of the ball clamp is based on the digital model developed using the 3D computer graphics tools.

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