**Justification of the structure and analysis of functioning of the device for tensioning prestressing strands**

I M Kutlubaev*, E Yu Matsko and V A Samigullin  
Department of Mining Machines and Transport-Technological Complexes, Nosov Magnitogorsk State Technical University, 38 Lenin Street, Magnitogorsk, 455000, Russia  
*ptmr74@mail.ru  

**Abstract.** The problem of creating a compact device for tensioning prestressing strands used for strengthening the surface of workings in mines is considered. It is proposed to use a lever mechanism with a variable structure for providing movement in several degrees of freedom. The geometrical parameters of the mechanism for obtaining the required displacements and forces are determined. The design of the device allows its use by one executive without involvement of hydraulic or electric drives.

1. **Introduction**

Prestressing strands (PS) are widely used: in construction activities for prestressing structural elements of constructions [1, 2], in mining operations for strengthening the mine surface [3]. Due to creation of a controlled axial tension, PS provides: in structural elements - increased load capacity, in mountain groups – the exception of falls.  

PS installation is carried out with a minimum set of connecting parts and is relatively easy to implement in stationary conditions. The technological scheme includes: laying the strand in the structural element, capture and tension of PS, fixing the end of PS at a given load using a split collet clamp. The most important is the operation of capture and tensioning PS. The capture of the end of PS is performed by a collet clamp driven by an individual drive. PS tension in production of building structures is carried out by a hydraulic tensioner [1]. Its use is possible when the length of the PS free end is not less than 200 ... 300 mm.  

Conditions of performing works in manufacture of building structures elements and mining operations are significantly different. Works on strengthening a mine surface are carried out in constrained conditions, at height [4]. In this regard, it is not possible to use the existing equipment in new conditions.  

For installation and tensioning PS strengthening the mine surface special mechanized complexes [5] are developed abroad. Due to known circumstances, approved technologies and related equipment are not available to Russian enterprises. In this regard, it became necessary to develop a device for tensioning PS adapted to mine conditions.
2. Statement of a problem

Conditions of mineral production becoming more complicated determined the need for transition from PS freely installed in the bore to prestressed PS [4]. At the same time, the design of PS coupling node – mine surface (Fig.1) as well as technological requirements have changed.

![Figure 1. Construction of a PS coupling node – strengthened surface and fixing details: 1 - working collet, 2 – working socket, 3 – support plate.](image)

PS should have a length of the free part (protruding from the bore) not more than 150 mm. PS tension should be at least 50 kN, preferably 90 kN. The tensioning device must have a low weight, dimensions and be mobile. The time for tensioning one PS should not exceed 2 - 3 minutes. Required PS tension force should be provided without the use of a hydraulic drive.

3. Analysis of the process of the PS tensioning

The PS tensioning includes five successive stages: the capture of the PS end, the preload of the base plate 3 to the mine surface, tensioning the PS end, pressing the collet 1 into the socket 2, releasing the PS end.

All stages differ in output links, carrying out active actions, direction of their movement, the acting forces. The PS tensioning process can be carried out on the basis of two fundamentally different configurations for constructing structural schemes of the device. In accordance with the first configuration, several drives are used, each of which provides the movement of its own output link [5]. Its implementation is associated with an increase in the mass of the device and complexity of the design.

The second possible variant is a creation of a device with an unstable structure. In this case, the schematic structure of the device initially has several possible degrees of freedom, but at each timepoint only one of them is realized. The general ideology of construction of such structures is developed and applied to adaptive grippers [6, 7]. The transition from one structure to another is realized using additional functioning links [8, 9] performed in the form of flexible elements. The condition of transition from the \( i \) variant of the structure to \( i + 1 \) is the force impact on the flexible element. Its deformation by a given value provides the change of the structural scheme.

4. Design of the tensioning device

Fixing elements of PS are not comprised in the device, but they are involved in the process of tensioning and fixation.

The device for PS tensioning and fixing includes a framework 4 with placed therein on cylindrical surfaces sockets: working 2 and blocking 5 (Fig.2). Sockets are separated from each other by a partition of the framework 6. The sockets comprise gripping collets: working 1 (in the socket 2), blocking 7 (in the socket 5). Gripping collets are connected with the sockets on conical surfaces. In the working socket 1 the cone angle \( \alpha \) is performed in the range from 11 to 21 deg. In the locking socket 5 the cone angle \( \beta \) is in the range from 4 to 11 deg. Between the partition 6 and the socket 2 a spring washer 8 is placed.
Figure 2. Device for the PS tensioning: a – initial position, b – end position.

The framework 4 is connected with the blocking socket through the lever mechanisms 9 and 10. The mechanisms 9 and 10 are identical and arranged symmetrically with respect to the longitudinal axis of the framework 4. Each mechanism includes: drive lever 11 and connecting rod 12. The framework 4, the lever 11, the connecting rod 12, the blocking socket 5 are connected in series by rotating pairs 13 - 15. Distance between the axes of rotational pairs: 13 and 14 – $l_{AB}$, 14 and 15 – $l_{BC}$, 13 and 15 (along the normal to the longitudinal axis of the device) – $t$.

The stages are characterized by the parameters presented in the table 1.

| Stage | Movement | Elements of the force interaction | Effective force / direction | Output link |
|-------|----------|-----------------------------------|----------------------------|-------------|
| 1     | Capture of the PS end | The PS end | $F_1$, to the strengthening surface | Framework 4 |
| 2     | Clamp of the support plate | Socket 5 - support plate 3 | $F_2$, to the strengthening surface | Framework 4 |
| 3     | PS tensioning | Socket 2 - socket 5 | $F_3$, from the strengthening surface | Socket 2, socket 5 |
| 4     | Pressing of the collet | Framework 4 – collet 1 | $F_4$, to the strengthening surface | Framework 4 |
| 5     | Releasing the PS end | Collet 7 –the PS end | $F_5$, from the strengthening surface | Framework 4 |
5. Work of the tensioning device
The first stage. Preparation for tensioning and fixing the PS is carried out. At the PS end is installed the support plate 3, put on the working socket 2 with the collet 1. The levers 11 in the initial position are divorced from the vertical to the angle $\gamma_1$. The framework 4 is moved towards the socket 2. The PS end is included in the collet 7. The external force $F_1$ is applied to the framework 4 and directed to the surface to be strengthened. After including the PS end into the collet 7 to its end protruding from the framework 4, an effort not exceeding $F_1$ is applied. This ensures the fixation of the collet 7 at the PS end.

The second stage. The levers 11 are rotated by an angle $\gamma_2$. The blocking socket 5 is stationary. Movement from the lever 11 is transmitted to the output link - the framework 4. Shifting to the strengthening surface, it transmits through the spring washer 8, the socket 2 force $F_2$ to the support plate 3. Contraction to the surface to be strengthened is provided. The stage ends when the force $F_2$ reaches the value providing deformation of the spring washer 8.

The third stage. Further rotation of the levers 11 at an angle $\gamma_3$ leads to an increase in the distance between the socket 5 and the socket 2 by the amount of deformation of the spring washer 8. The force acting between the output links is increased to the value $F_3$, sufficient for full compression of the washer 8. The stage ends after reaching the collet 1 by the partition 6.

The fourth stage. Levers 11 rotate by an angle $\gamma_4$. The socket 5 is stationary, the framework 4 moves to the strengthened surface together with the collet 1 including it into the socket 2 with the force $F_4$.

The fifth stage. Removing of the device from the PS end. Levers 11 are unset. The framework 4 moves to the surface being strengthened. The collets 7 unclench, releasing the PS end.

The value of the operating cycle of the output link is determined at each stage by the angle of rotation of the lever $\gamma_i$ and is determined by the expression

$$h_i = l_{AB} \sin \gamma_i + l_{BC} \left(1 - \left(l_{AB} \cos \gamma_i + a \right) / l_{BC}\right)^2 \left(l_{BC} - \left(l_{AB} + t \right)^2\right)^{0.5}$$

(1)

With the accepted parameters $l_{AB} = 25$ mm, $l_{BC} = 70$ mm, $t = 10$ mm the angles of rotation $\gamma_i$ corresponding to each stage and the corresponding angle of the operating cycle $h_i$ (table.2) are determined. The total displacement of the framework 4 is 23 mm.

Table 2. Parameters characterizing the stages of the PS tensioning

| Stage $(i)$ | Rotational angle of the lever $\gamma_i$, deg | Operational cycle $h_i$, mm | Differential ratio | Force, N |
|------------------|---------------------------------|----------------|-----------------|----------|
| 1                 | 8.7                             | 0              | 1               | $F_1 = 68$ |
| 2                 | 16.8                            | 4.9            | 42.1            | $F_2 = 6596$ |
| 3                 | 59.7                            | 20.1           | 96.7            | $F_3 = 18782$ |
| 4                 | 87.6                            | 23             | 165.4           | $F_4 = 79630$ |
| 5                 | 8.7                             | 0              | 1               | $F_5 = 68$ |

The force on the output links was determined using the grapho-analytical method [10]. The length of the lever 11 was taken 540 mm. The results are shown in table 2. The maximum force generated on the levers 11 for providing $F_i$ is 272 N.

On the basis of a detailed study of the design of the tensioning device, it was found that the total weight is 5.2 kg.

6. Conclusion
1. Strengthening of the mine surface using the PS with pretension may be performed by a mobile device with a mechanical drive.
2. The use in the construction of the mechanism of an unstable structure ensures the implementation of all stages of actions for the PS tensioning from one drive.
3. Lever mechanism allows reducing the external force in the range from 42 to 165. This ensures the required force impact at all stages of PS capture and tensioning without the use of hydraulic or electric drives.

References

[1] Musikhin V A 2016 Advantages of Prestressed Steel Strand with Point Contact of Wires Bulletin of the South Ural State University. Ser. Construction Engineering and Architecture. 2 (16) 11 (in Russ.). DOI:10.14529/build160202

[2] SP 52-102-2004 2005 Predvaritel'no napryazhennye zhelezobetonnnye konstruktsii [SP 52-102-2004. Prestressed concrete structures] Moscow, Gosstroy of Russia

[3] Anufriev V E, Pozolotin A S, Renev A A, Rytkhovskiy V M, Samoletov Y Y 2004 Opyt doprochneniya kanatnymi ankerami krovli vyrabotok, sohranyayemyh na granice s vyrabotannym prostranstvom [Experience of the complete hardening with the cable anchors of the roof of the workings, stored at the border of the developed space] Bulletin of the Kuzbass State Technical University. 2 55

[4] Eremenko V A, Razumov E A, Zayatdinov D F, Pozolotin A S, Prohvatilov S A, Krasilov S Y 2013 Sovremennoe strengthenovanie dvuhurovnevoj tekhnologii ankernogo krepleniya shirokih sopryazhenij gornyh vyrabotok [Improvement of two-level technology of anchorage of wide interfaces of mine workings] Gorny informatsionno-analiticheskij byulleten [Mining informational and analytical Bulletin]. 5 20

[5] Fischer G, Ruiz-Tagle J, Bucher R, Luis R 2017 Ground support installations, using a mechanised unroller and flexible high-tensile strength chain link mesh 8th international conference on deep and high stress mining, Australian Centre for Geomechanics in J Wesseloo (ed.), Perth.

[6] Bogdanov A, Permyakov A, Zhdanova Y 2018 MATEC Web of Conferences 161, 03009 DOI: 10.1051/matecconf/201816103009

[7] Bogdanov A, Permyakov A, Zhdanova Y 2018 MATEC Web of Conferences 224, 01029 DOI: 10.1051/matecconf/201822401029

[8] Kutlubaev I M 2004 Ispol'zovanie strukturnykh shem dlya analiza mnogodvigatel'nyh mashin [Using schematic structures for analysis of multi-engine machines] Vestnik mashinostroeniya [Bulletin of mechanical engineering]. 12 8

[9] Makarov A N, Kutlubaev I M 2006 Sintez struktur mnogodvigatel'nyh mashin s kinematicheskoy razvyazkoj dvizheniya osnovnyh ispolnitel'nynh zven'ev [Synthesis of structures of multi-engine machines with a kinematic decoupling of the movement of main executive units Vestnik of Nosov Magnitogors State Technical University]. 1 (13) 37

[10] Artobolevskij I I 1975 Teoriya mekanizmov i mashin [Theory of mechanisms and machines] Moscow, Nauka