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CONSTRUCTIONAL FEATURES OF ROPES IN FUNCTIONAL UNITS OF MINING SHAFT HOIST

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Abstract: In this paper structural analysis of steel ropes applied in mining shaft hoists was conducted. Functions of the ropes which they fulfilled in these shaft hoists were identified. Expected operational features of ropes were indicated too. An analysis was carried out four identified groups of ropes: hoisting ropes, balance ropes, leading rope and fender ropes. Basic constructional features: geometrical and material of ropes, which they should be characterized in each of mentioned functional groups were indicated. Constructional structures of mentioned steel ropes, the most often applied in domestic mining shaft hoists were described. Observed tendencies in analyzed issues also were shown.

Key words: Shaft Hoist, Steel Rope, Hoisting Rope, Balance Rope, Leading Rope, Fender Rope, Operational Feature, Constructional Feature

1. INTRODUCTION

The ropes as the element or the elements set are appearing in numerous, diverse machines and mechanisms, fulfilling the most different functions in them. They are elements used, for example, as flexible connector in control systems, they are used also for an transfer operation of axial load in changeable directions in transport systems, both horizontal and vertical.

As the constructional element moving axial forces with significant values steel ropes are applied, e.g.: in the construction (goods and personal lifts, reinforcing concrete), in the mining for the vertical and horizontal transport and in other branches of industry, as a different kind of tension members, being used for a transport of materials and people.

Relatively great durability and a reliability are a major advantage of ropes. This second feature results from it, that the rope has a parallel constructional structure what causes, that in case of damage one or a few structural components (wire) loss of the ability of the whole system, in which its is existing isn't taking place (Guo et al., 2017; Olszyna et al., 2013, Peterka et al., 2014; Sioma and Tytko, 2012; Zhang et al., 2017).

2. ROPES IN MINING SHAFT HOISTS

Mining shaft hoists are a very representative example of the object being used for a vertical transport, of both the staff of the mine and winning. Their depth is diversified and in Polish mines of the hard coal is coming up to 1300 meters. Among others for this reason constructional structure of shaft hoists is diversified. In addition, in each of variants existing individual ropes or set of ropes which fulfilling the following functions:

– carrying – moving total axial load coming from hung mass: of hoisting dishes, suspensions, ropes, transported mining, material or people,
– balancing – being used to balance out the static moment resulting from the imbalance of mass on both sides of the driving wheel,
– leading, which providing the free migration of dishes in the mineshaft is a task,
– fender – limiting lateral movements of dishes in the mineshaft.

Situating them in the standard mineshaft was presented in Fig. 1.

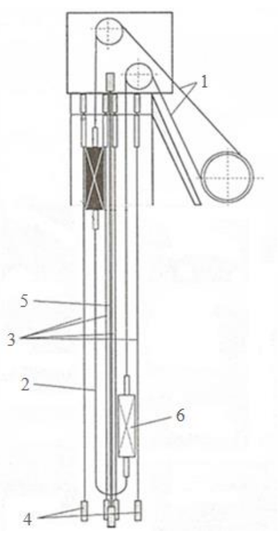

Fig. 1. The ropes in the exemplary mining shaft hoist: 1 – hoisting rope, 2 – balance rope, 3 – leading ropes, 4 – weights of leading ropes, 5 – fender ropes, 6 – hoisting dishes

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From the above statement it appears that ropes in mining lifts are fulfilling number of diverse functions. It is a reason, that applied in them ropes have various constructional solutions and the structure. They differ between themselves above all in structural features: geometrical and material what he causes that also their operational features are diversified. Using the rope with the specific construction depends first of all on the function which it is supposed to carry out (Chang et al., 2016; Wang et al., 2015; Zhang et al., 2017).

2.1. Hoisting ropes

Hoisting ropes in mining shaft hoist are working in different layouts, depending on the type of the drive:
- in drum drives – rope working in the overlap or underlap arrangement,
- in drives with the frictional contact (KOEPE system) – in arrangements one-, two- or four-ropes.

In multi-rope systems essentially is that ropes work identically, not entering undesirable disruptions into the system (Chang et al., 2017; Ma and Xiao, 2013; Ma and Xiao, 2016; Styp-Rekowski et al., 2015). For this reason it necessary is to apply in the system the identical number of left- and right-lay ropes, because it allows to minimize tendencies of turning the hoisting dish. Moreover, hoisting ropes in multirope arrangements should be produced from one party of wire rods and in one production cycle. It is stated practically by authors (Mańka, 2013; Mańka and Styp-Rekowski, 2009) that in multi-rope arrangements the use of ropes dating from different supplies in the significant range is shortening the time of their use.

One already stated above that for correct and effective fulfilling assumed functions, selecting the constructional features suitable for the function of ropes was essential.

In case of hoisting ropes first of all one should rank significant material constructional features: the chemical composition of the wire rod which wire is produced from – basic structural element of a steel rope. Tensile strength, that is a quantity determining the basic functional feature of hoisting ropes depend on its chemical composition – acceptable tensile force. On account of the fact that the hoisting rope is repeatedly bent also plastic properties of wire, as well as the whole rope are significant. Such features provides a wire rod of steel contents within carbon in the range of 0.3 ÷ 0.9%, of manganese in the amount 0.3 ÷ 0.8%, and up to the 0.2% of such metals as: chromium, nickel, copper. Such elements as: sulphur and phosphorus should not be altogether more than a 0.05% on account of the fact that they are granting the undesirable brittleness of steel.

A core is an important element of the constructional structure of round hoisting ropes, above all material from which it is made. It is responsible for an appropriate shape of the rope, moreover, it is an axis of the moment of stranding back of the whole rope, resulting from the constructional structure of ropes and from the way of producing them. In hoisting ropes to main objectives of the organic core belong:
- providing the "support" for rope strand so that in operating time contact between them doesn't take place,
- counteraction for considerable radial pressures and minimizing deformations of the section diameter of the rope,
- protecting the inside of the rope (of wire and strands) against the corrosion.

Currently, in the domestic mining shaft hoist round or triangle strand single-layer ropes are applied. Their constructional structures were presented in Figs. 2 and 3.

In Fig. 2 ropes were shown structures of round strand ropes of type Warrington-Seale (WS) and Warrington-Cover (NW).

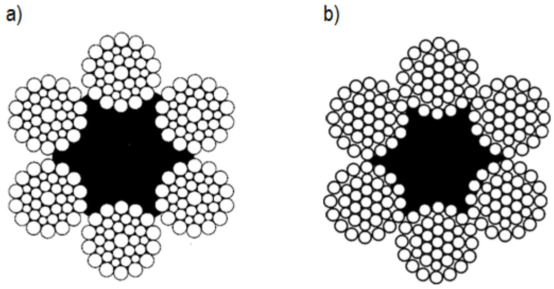

Fig. 2. Examples of structures of round strands hoisting ropes: a) type 6x36WS-FC, b) type 6x35NW-FC (Catalogs of rope manufacturers)

The ropes presented in the picture above (Fig. 2) are made of a round strands which are rising as a result of winding on spinal wire next layers of wire. In Fig. 2a the structure of the rope of the type Warrington-Seale was presented, in which among layers of wires in strands a linear contact of wire is appearing, however in Fig. 2b – the rope of the type Warrington-Cover, in which between last and one before last layer of wires in strands point contact is appearing.

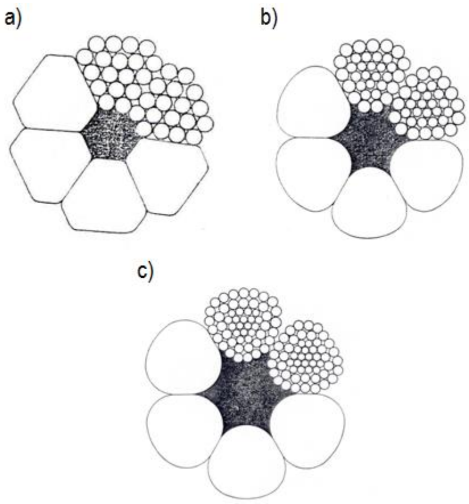

Fig. 3. Examples of structures of triangle strands hoisting ropes: a) type 6xV18B-FC, b) type 6xV33B-FC, c) type 6xV54B-FC (Catalogs of rope manufacturers)

Triangle strand ropes – Fig. 3, are made according to the Polish Standard PN-66/G-46602. In these ropes to the triangular core of strand, made from three pairs of round wire and three wire filling up (3x2+3), is rolled up one (Fig. 3a), two (Fig. 3b) or three (Fig. 3c) the layers of wire of various diameters. Diameter of the triangle strand rope depends on the diameter of wires in particular layers and numbers of wires in strands.

Multilayered hoisting ropes type Notorplast are applied in deep mineshafts. They are screwed together of around strand – Fig. 4. Ropes of the such structure are characterized by great unscrewness, and tensile strength of wire is included in the range of 1770 ÷ 2000 MPa. Between the centre and outer layer they have a greased plait made of sisal fibres. The important task of

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plait, apart from the corrosion protection, is reducing surface pressures between the outer and inner layer.

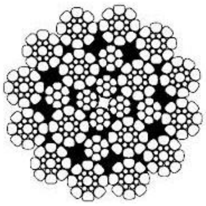

Fig. 4. Structure of multilayer hoisting rope firm ArcelorMittal Wire (France), type Notorplast 12x16 SPC: PWRC [FC-4x7-(4x17S+4x7)] (Catalogs of rope manufacturers)

For a few years a tendency of replacing described higher ropes is being observed, especially a triangle strand ones, by ropes with other constructional structures, first of all with compacted ropes – Fig. 5. Such ropes are built of strands with the linear contact of wire, subjected to plastic forming. After this processing a surface contact of wire in strands is being get.

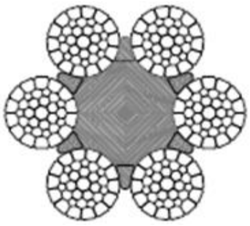

Fig. 5. Structure of hoisting rope type 6xK36WS-FC with surface contact of wires in plastic deformed strands (Catalogs of rope manufacturers)

With advantages of compacted ropes, in comparing to traditional ropes, are among others: greater filling of the diameter, smaller unscrewness moment, the greater resistance to wear, abrasion, the corrosion and the greater tensile strength (Carbogno et al., 2010; Zhao et al., 2017; Peng et al., 2016).

2.2. Balance ropes

In order to protect against the possibility of the appearing of the unchecked slide in the arrangement: hoisting rope – driving wheel (lineshafting), and also for balancing the static moment resulting from the imbalance of mass on both sides of the driving wheel, in mining shaft hoist balance ropes are applied. These ropes should have appropriate mass individual, to be characterized unscrewness, the great durability, but especially a resistance to the effect of the aggressive environment. Based on literature information, e.g. in the papers of authors (Carbogno et al., 2005; Li et al., 2017; Mateja and Pojnar, 2005; Xu et al., 2014), as well as on results of authors own investigations, e.g. (Styp-Rekowski and Mańka, 2010), the time of life of steel balance ropes in the large degree depends exactly on the environment, in which they are operated. In order to minimizing the corrosion effects, wires of round ropes are covered with the protective coating. In domestic ropes to the protective coating of wire zinc is applicable, foreign producers apply also an alloy of zinc and aluminum (galwan).

Direction of a lay of wire in strand and strands in the rope, is a next essential geometrical constructional feature of balance ropes. Flat steel ropes and steel-rubber ropes are built from the same number of the right-lay and left-lay ropes what causes, that ropes of this type are unscrew.

A contact of wire appearing between particular layers in the strands and individual layers of strands in multi-layer ropes is a next important constructional feature of steel balance ropes. On account of the durability of ropes one endeavour to situation, that it will not point contact.

In traditional solutions, as balance ropes round multi-layer ropes are applied – Fig. 6, made according to Polish norms or company conditions of the producer. They were applied in shaft hoist about the depth to 1300 m. Parameters of wire lay in strands and structure of strand in ropes are so well-matched that these ropes aren't having a tendency to the rotation against the own axis. Round strand balance ropes have two (Fig. 6a) or three (Fig. 6b) layers of strands.

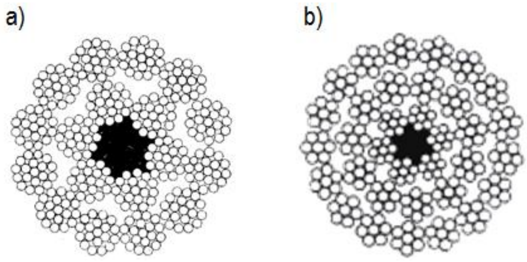

Fig. 6. Examples of round balance ropes structures: a) two-layers type 18x19M-FC, b) three-layers type 33(M)x7-FC (Catalogs of rope manufacturers)

Two-layers round balance ropes of the domestic structure are built from wires of the identical diameter. In mentioned types of ropes a point contact is appearing between wires in strands and between strand layers in whole ropes. In order to getting the optimum shape of strand, three-layers ropes have spinal wire of the diameter 0.1 mm bigger than wire of strand. In foreign ropes as a result of strand making of the various diameter wire and of using inserts of natural or artificial fibres, the contact between wire and layers isn't punctual.

The elasticity of steel ropes with such constructional is possible to obtain thanks to the great number of strands. Multilayer round balance ropes during the operation ought to have ensured a possibility of pivot in rope suspension due to the resultant moment acting there (from the load) twisting off strands.

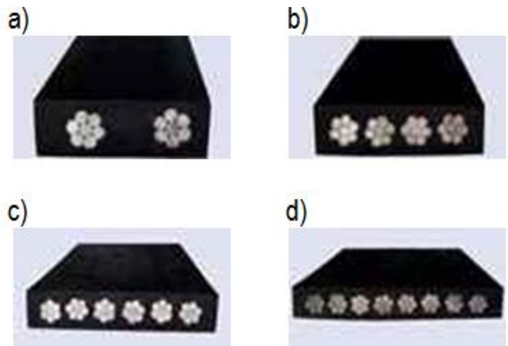

Fig. 7. Structure of steel-rubber balance ropes type SAG: a) 2-ropes, b) 4-ropes, c) 6-ropes, d) 8-ropes (Catalogs of rope manufacturers)

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At present, in the predominating number of cases, as balance ropes steel-rubber ropes are used – Figs. 7 and 8, which characterize the great fatigue durability, resistance to action of the corroding environment and on little blows of falling objects (mining). At the appropriate technology of making, they can be applied in shaft hoists depths above 2200 meters.

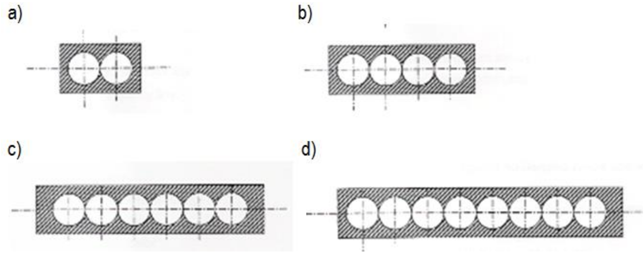

Fig. 8. Steel-rubber balance ropes type ZEP: a) two-ropes, b) four-ropes, c) six-ropes, d) eight-ropes (Catalogs of rope manufacturers)

Basic advantages of steel-rubber ropes, given by authors: (Hansel, 2000; Kwaśniewski, 2010, Milcarz and Fundament, 2005) are following:

- unscrewness,
- the great corrosion resistance and blows of small falling objects,
- possibility of repair of the rubber coating in places of mechanical damages with method of the vulcanization or the adhesive bonding,
- the lack of the need of additional lubrication,
- antistatic-ness, letting for applying in exhaust shaft hoists carrying out air from each type of methane fields,
- possibility of control of the technical condition with applying non-destructive testing with magnetic method at the producing plant and during the operating.

Steel-rubber ropes in their structure have steel cables alternately – right-lay and left-lay ropes, which are in the rubber coating. The weight of the steel-rubber rope depends on the number and the diameter of steel cords and on the thickness of the rubber coating.

Both types of ropes (SAG and ZEP) are usually produced of thicknesses 29 or 35 mm. In order to reach the right specific weight and transverse dimensions of the rope, transverse dimensions of the rope can be changed as a result of arrangements between the producer and the user.

Core in steel-rubber ropes types of SAG and ZEP, which is in the form of steel links strand, is made identically like remaining strands of ropes. It is structure with the linear contact of wire of the type WARRINGTON.

2.3. Leading and fender ropes

Leading ropes are applied in shaft hoists where instead of stiff leading of dishes (steel or wooden guides) a rope guidance was applied. Providing the free, but defined displacement of dishes in the shaft hoist is the main task of these ropes.

Limiting lateral movements of dishes in the shaft hoist is the task of fender ropes. Similar functions of leading and fender ropes in mining hoists causes, that in both cases ropes are applicable with the same constructional structure.

Leading and fender ropes can be applied in shaft hoists of the depth more than 1000 m, in which providing the rectilinearity of stiff leading of dishes is labor consuming and uneconomical. Hoisting dishes are being led by ropes in exchangeable sliding or sliding-rolling tracks attached to dishes.

Leading and fender ropes in shaft hoists have closed or half-closed structure. Ropes of this structure are characterized of "smooth" surface, unscrewness, corrosion and abrasive resistance, great tensile strength, and great crosswise and longitudinal stiffness. The tensile strength of wire in ropes of the closed and half-closed structure should take out from 780 to 1470 MPa. Tolerance of the tensile strength for individual wire of leading ropes according to standard (PN-EN 12385-7:2004) should not cross +250 MPa.

In Fig. 9 two typical solutions of applying leading and fender ropes were presented:

- corner arrangement, in which leading ropes are located in corner of the hoisting dish – Fig. 9a,
- side arrangement, leading ropes are arranged along one side of the hoisting dish – Fig. 9b.

Corner arrangement – Fig. 9a, is more resistant to action of the unscrew moment of hoisting rope. Side arrangement – Fig. 9b, is recommended at multi-ropes system of hoisting ropes, in which unscrew moment, as a result of applying the same number of right- and left-lay, practically is not appearing.

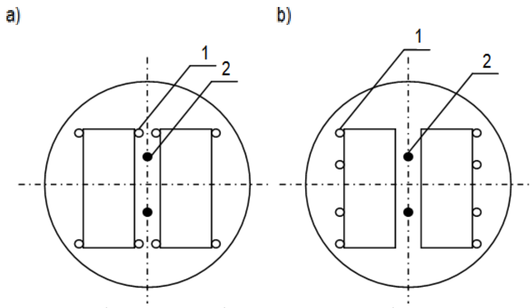

Fig. 9. Location of leading and fender ropes in shaft hoist in arrangements: a) corner, b) side; 1 – leading ropes, 2 – fender ropes

Arranging presented in Fig. 9 of leading ropes around dishes are the most often applying solution in domestic shaft hoists. In the world it is possible to meet a lot of other solutions of these ropes arranging around the dish, it is regarding both the number of ropes and the way of arranging them around the dish.

In newly built or modernized shaft hoists, for leading the dish round strand, ordinary-lay, non-spinning leading ropes are applied. Leading ropes in that kind of hoist, apart from leading the dish are usually also hoisting rope of the service platform hanging in the shaft. These ropes one end are being fixed to the platform and second, through directional wheels on the tower of hoist to the drum situated on the framework. On the drum a remaining rope-length which is used to raise or to leave the working platform. The dish is led by the leading sleigh installed above it on the rope. Tensile strength of wires of this kind of ropes is 1570 MPa and more, depending on requirements ordering.

In mining applicable regulations essential requirements concerning leading and fender ropes operating in domestic shaft hoists were determined. They contain, among others:

- demanded minimal safety factor understood as the quotient of real tensile force of rope in one piece to the maximum of static load,
- number of leading and fender ropes depending on air flow rate in the shaft,

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– way of leading ropes arranging around the dish and fender ropes in the shaft,
– the kind, the way and the value of the tension of ropes in sump or in tower of the shaft,
– diameter of fender ropes; it should be 2 mm bigger than leading ropes.

Leading and fender ropes, the most often of closed and half-closed structure, belong to a type of twisted line ropes. Next layers of round wire are being wound on central spinal wire, and then, depending on the structure and donating the rope – shaped wires. For getting almost total unscrewness of that kind of ropes, lay directions of wire in particular layers are closely determined in standard.

Half-closed ropes are built of a few layers of round wires, however outer layer alternately arranged round wire and profile wire.

In ropes of the closed structure according to the standard (PN-EN 12385-7:2004), on layers previously screwed together of round wire, a layer of alternately arranged wire shaped (X) and round is wound, and then layer of other shaped wire (Z).

Using wedge-shaped wire in structures of this type of ropes causes, that they are characterized by an increased stiffness what for the function carried out is not a negative feature. Important factor causing that ropes of the closed and half-closed structure have a abrasive and corrosion resistance there are transverse dimensions of profile wire. Transverse dimensions of profile wires, especially their height and diameter of the wire in the outer layer of the half-closed structure can be into 10 mm. Detailed requirements concerning dimensions of wire of outer layer for ropes of the half-closed structure are given in the standard (PN-EN 12385-7:2004). Dimensions of profile wire in ropes of the closed structure are determined by the producer of the rope. In the outer layer usually they have a height of about 6 mm. It is an essential requirement, if only structure of closed and half-closed structure ropes a creates possibility of keeping cracked wire in the contour of ropes, because cracking and weaving of profile wire can lead to the stop of hoisting shaft.

Round strand leading ropes belong to double-laid ropes. They are made by winding on the fibre core one or more layers of strands. Round strand ropes single-layer are making as ordinary lay with aim of getting the smallest unscrewness. In these ropes laid direction of wire in strands is against to laid direction of strands in the rope.

Conducted analysis of types of leading and fender ropes operating in domestic mining shaft hoists showed that the most often ropes of below described structural solutions were applied. In Figs. 10-12 a few structural solutions were presented. Constructionall structure of ropes of the structure half-closed and closed is more compound than the around strand ones, therefore the marking is more compound. In denotation of ropes symbols according to the applicable standard (PN-EN 12385-2:2008) were accepted.

In Fig. 10 half-closed ropes were shown. Rope of structure 1 + 6 + 7 / 7 H (Fig. 10 a) is a rope having in outer layer alternately, 7 profile wires (H) and 7 round wires. The internal layer of this rope is screwed together from 7 round wire (1 + 6).

Rope of structure 1+6+6/ 6+9/9 H in Fig. 10 b, in outer layer has 9 wires alternately, profile (H) and 9 round wire. The internal layer of this rope is screwed together from round wire in the amount of 1+6+6/6.

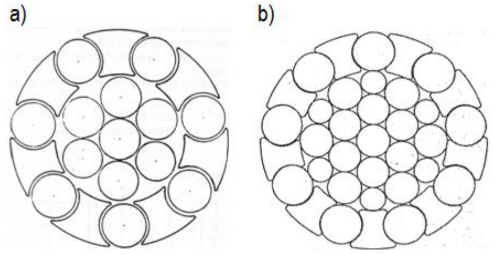

Fig. 10. Exemplary constructional structure of half-closed ropes (Catalogs of rope manufacturers)

In the next picture ropes of the closed structure were presented. The rope produced of LINODRUT company, for which the structure was presented in Fig. 11a, in outer layer has 23 profile wires (Z). Next layer constitutes 17 profile wires (S). Inside of this rope is screwed together from round wire in the number: 1+6/ 6+12+18.

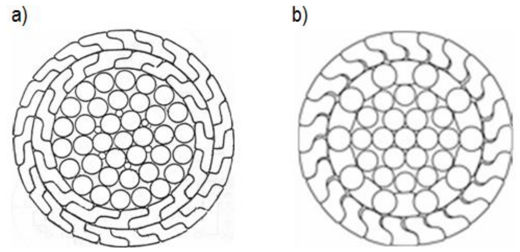

Fig. 11. Exemplary cross section of closed ropes of structures: a) 23Z+17S+18+12+6/6+1, b) 24Z+10/10H+12+6+1 (Catalogs of rope manufacturers)

Rope of the Teufelberger company (Austria) – Fig. 11b, in outer layer has 24 profile wires (Z), next layer it is alternately arranged 10 profile wires (H) and 10 – round wires. The internal layer of this rope is screwed together from round wire in the amount of 1+6+12.

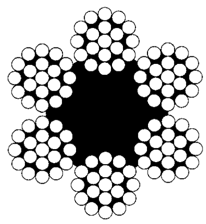

Fig. 12. Cross section of round strand rope, type 6x19M-FC (Catalogs of rope manufacturers)

In Fig. 12 a structure of the round strand rope was shown. This rope is built of 6 strands containing 19 wires with point contact of wire in strands (marked M), with the fibre core (marked FC).

3. CLOSURE

Above, chosen examples of the construction of more often appearing ropes: hoisting, balance, leading and fender were presented. In individual cases, in which different criteria than one gave higher are considered, applied ropes can be of other constructional structure.

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On the base of conducted, and described in this work the functional and structural analysis of various constructional solutions of steel ropes applied in shaft hoists, following conclusions were formulated:

– produced ropes are characterized by great structural diversity but simultaneously not very great versatility. Mentioned factors cause, that ropes still are objects of numerous researches fulfilled by scientific and scientific-research centers,
– at depths of shaft hoistings over 500 meters multi-layer ropes, which are characterized of great unscrewness are applied,
– structural diversity of ropes – particularly multi-layers causes, that the evaluation of the current rope technical condition is complicated and requires great experience from conducting an examination,
– discerning, multifactorial analysis preceding the decision to use the rope in the mechanism of the determined structural form is contributing undoubtedly to increase the effectiveness of carried out action, among other thanks to the possibility of the optimization of choice in this range, at logistic criteria.

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