Innovative Solution for the Transport of Wire Ropes of Large Size and Length

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Abstract. This paper presents the study about the development of an innovative solution for road transport of high dimensions and lengths wire ropes. Currently these operations are limited by various constraints related both to the maximum weight and to the dimensions, even when using special vehicles, the passage of the load on the road becomes impossible. The proposed solution involves the use of two reels positioned on two separate trailers. In this case, the overall dimensions are reduced and the maneuverability of the load is considerably increased. The research is based on a concrete case in which the results relating to the sizing of the reels and the wire rope winding system are also reported, for the transport of a wire rope with a diameter of 125 mm and a weight of 400000 kg. The research therefore shows that through this solution, which can also be extended to several vehicles connected to each other, the transport of wire ropes of large dimensions and length is achievable partially releasing the problem of dimensions and road travel.

1. Introduction

The subject of this paper is the study of an innovative method of transporting wire ropes of large dimensions and lengths, usually used for structural uses, like the mining sector and the off-shore industry. In fact, compared to the transport of other types of goods and materials, the transport of wire ropes, it has some peculiarities attributable largely to the shape of the reels, which have a cylindrical geometry and therefore are more bulky if compared, with the same weight, to squared geometries used, for example, for the construction of electrical transformers. The road transport, by industrial vehicles, also presents problems related to legislative aspects concerning transport (e.g. the maximum weight per axle) and the presence of possible obstacles present during the journey to transport the reel from one place of interest to another, for example from the place of production to the port to then be taken to the place of use. For these reasons, the type of vehicles for the transport of reels and their number is not efficient and plausible for the transport of large diameter and long length wire ropes. With these problems, the aim of this work is to present a possible alternative solution for the transport of large reels, this solution is based on the subdivision of a single large reel into two or more reels of smaller dimensions so as to be able to be transported with more readily available and maneuverable vehicles. At the production site, the wire rope is wound on several reels and positioned on different industrial vehicles; once they reach their destination, the reels must be rewound to form a single reel. The present study, after an evaluation of the problem, also based on the state of the art, finds concrete application in the transport of a 125 mm diameter wire rope, 4000 m long and with a total weight therefore equal to about 400000 kg.
2. Conceptual development of a new reel transport system

In order to develop a new transport solution, first of all, we proceeded with the study of possible methodologies and solutions, considering: the maximum load height, the overall dimensions and finally the availability of a trailer suitable for both weight and to the volumes related to the transported load, it has also been seen that the optimization of the chassis does not significantly reduce the total weight [1] [2]. Figure 1 show the two different construction solutions adopted for the transposition of large reels.

![Possible transport configurations.](image)

(a) Semi-trailer trolley available for loads of less than 200 tons, not usable for large reels as the imposed height limits would be exceeded.
(b) Trolley for 300/400 ton transport, the problem related to height is solved, but the longitudinal dimensions and the turning radius are increased (solution adopted for the transport of large reels).

In this work the two innovative solutions shown in figure 2 will be developed.

![Possible innovative configurations for the transport of reels.](image)

(a) The first solution of figure 2 (a) refers to the transport of two coils of the same size via two trailers towed by two different trucks, in this way it is possible to use trucks with a maximum capacity of 200 tons.
(b) The second solution differs because the transport is for two reels of different sizes, in this way it is possible to use two trailers towed by the same truck. The solutions of figure 2 are two innovative solutions which have many advantages compared to the traditional solutions of figure 1 which are currently used for the transport of large diameter reels. The two proposed solutions, given by the wire rope wound on two or more reels, are the most convenient considering the use of equipment with smaller dimensions, in fact exceptional vehicles must be specially designed [3] and guaranteeing greater maneuvering capacity than, for example when the solution (b) is adopted, as can be seen from figure 3, which shows the comparison of the turning radius of the two different solutions.

![Turning radius comparison.](image)

3. Development of innovative reel for transport

In order to use the chosen solutions, it is necessary to develop a new configuration of the transport reel system, a solution to reduce the weights of the reels and therefore take advantage of less performing transport systems could be use reels made with different materials [4], but this road is not feasible
because the actions that the wire rope exerts would be impossible for plastic materials. The new configuration of the reels must be composed of a reel capable of containing the entire wire rope, but with the particularity of being a decomposable reel and a temporary reel on which part of the wire rope will be wound. The reel must be decomposable, or, demountable. The two external discs must be reduced, when only a portion of the wire rope is wound, in order to reduce the total height of the system reel and vehicle. The reel must be reassembled when the height (or even width) constraints are no longer present, such as transport by ship. The size of a reel also depends on the maximum diameter of the wound wire rope, its length and its weight. In general, a coil is made up of different parts, as can be seen from figures 4 (1: drum, 2: square (to support the flanges); 3: flange; 4: drum head; 5: bush for rotation; 6: spindle support for winding. For the sizing and verification of the wire rope, the Eurocodes [5] have been adopted, in particular the standards relating to Eurocode 3 [6] [7].

![Figure 4. Main parts and characteristics of the reel.](image)

The development of the project concerns the concrete case referred to the Usha Martin company which needs to transport a wire rope of large dimensions, both in diameter and length, from the production site to the port. Currently the solution that the company adopts is a) of figure 1, however this solution is not feasible for the wire rope being transported, so it should be passed to solution b) of figure 1, but it is not feasible for a series of problems connected to the road route which should include, in addition to the removal of some road obstacles (traffic lights, signs, etc.) and the temporary closure of some motorway sections, the construction of special roundabouts to allow the transit of the vehicle b) of figure 1, which is absolutely impractical. For this reason, the solutions of figure 2 and in particular the solution (a) of figure 2 have been developed. The main characteristics of the wire rope to be transported are: nominal diameter $d_{wire \ rope} = 125\text{mm}$; maximum allowable diameter $d_{adm} = 130\text{mm}$; nominal length $L_{wire \ rope} = 4000\text{m}$; maximum admissible length $L_{adm} = 4060\text{m}$; maximum wire rope weight 400000 kg.

4. **Geometric sizing of the reel**

Based on these characteristics, it is possible to estimate the size of the reel through three different methods: volume equivalence, average length per loop and incremental method. We therefore opted for the incremental method, as it allows to calculate for each layer the exact length of wire rope that can be wound on the drum, remembering that at each layer the winding diameter increases allowing to contain more wire rope. It is important to underline that the diameter of the drum on which the wire rope is wound derives from various considerations table 1. A smaller wire rope winding diameter, determines greater stresses present in the wire rope, a greater force required for the winding and a smaller winding diameter of the whole wire rope, effectively reducing the height dimensions of the vehicle transport with coil. Based on these aspects, and primarily on the stresses induced in the wire rope as a result of the winding, a winding diameter of approximately 2000 mm has been adopted. In this case the ratio $D/d = 2000/125 = 16$. 

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[i]: href}
Table 1. Table for calculating the flange diameter.

| Layers | ϕ layer [mm] | Length [mm] | L. tot [mm] | n° loop | W [mm] | L. wire rope max [m] | c [mm] | ϕ fl [mm] | Choice criterion |
|--------|-------------|-------------|-------------|---------|--------|---------------------|--------|------------|------------------|
| 0      | 1910        | 0           | 6           | 633.5   | 82355  | 4060                | 1441   | 5052      | 82510            |
| 1      | 2170        | 6409        | 14          | 298.5   | 38805  | 4070                | 679    | 3788      | 38989            |
| 2      | 2430        | 7226        | 22          | 187.5   | 24375  | 4064                | 427    | 5453      | 24631            |
| 3      | 2690        | 8042        | 31          | 133.5   | 17355  | 4077                | 304    | 3557      | 17716            |
| 4      | 2950        | 8859        | 40          | 101.5   | 13195  | 4082                | 231    | 3672      | 13696            |
| 5      | 3210        | 9676        | 51          | 80.5    | 10465  | 4082                | 183    | 3836      | 11146            |
| 6      | 3470        | 10493       | 62          | 65.5    | 8515   | 4077                | 149    | 4028      | 9420             |
| 7      | 3730        | 11310       | 74          | 47.5    | 6175   | 4062                | 126    | 4243      | 8370             |
| 8      | 3990        | 12127       | 87          | 35.5    | 4615   | 4097                | 108    | 4466      | 7621             |
| 9      | 4250        | 12943       | 101         | 28.5    | 4115   | 4077                | 92     | 4694      | 7054             |
| 10     | 4510        | 13760       | 115         | 22.5    | 4155   | 4097                | 81     | 4932      | 6754             |
| 11     | 4770        | 14577       | 131         | 16.5    | 4082   | 4077                | 51     | 5173      | 6598             |
| 12     | 5030        | 15394       | 147         | 10.5    | 4190   | 4077                | 65     | 5420      | 6565             |
| 13     | 5290        | 16211       | 164         | 5.5     | 4183   | 4077                | 58     | 5666      | 6565             |
| 14     | 5550        | 17027       | 182         | 2.5     | 4093   | 4077                | 51     | 5912      | 6596             |
| 15     | 5810        | 17844       | 182         | 2.5     | 4093   | 4077                | 51     | 5912      | 6596             |

- Layers: number of layers of wire rope subsequently wound on the drum;
- ϕ layer: outer diameter of the nth layer of wire rope;
- Length: length of a loop of wire rope belonging to the nth layer;
- L.tot: sum of the development of all the previous layers (for ease of reading it is expressed in meters for each loop);
- n° loop: is the ratio between the nominal length of the wire rope in meters and the total length of one turn in meters, we proceeded to round up to the upper one and a half turn using the following algorithm
  \[ n°\text{loop} = \text{INT}\left(\frac{\text{L. wire rope}}{\text{Length}} + 0.499\right) + 0.5 \]  
- W: is given by the product of the number of turns for the admissible diameter of the wire rope;
- L. wire rope max: is the maximum length that can be wound on the reel, it is calculated based on the number of loop for the length of each loop;
- c (clearance): safety margin to prevent the wire rope from coming into contact with the ground \( c = 0.0175 \text{W} \);
- ϕ fl: is the effective diameter of the coil flange to be made, it is given by:
  \[ \phi_{fl} = \phi \text{layer} + 2 \star c \]  
- choice criterion: extrapolation of what is generally used for the design of the stranding machines. In practice it is the diagonal of the coil seen in plan and is given by:
  \[ \sqrt{\phi_{fl}^2 + W^2} \]  

Among the various dimensional combinations, the one with the choice criterion of lower value is considered preferable for its greater "compactness". By keeping the reel diameter and the wire rope length constant, it is possible to determine: the diameter of the flange, the number of layers and the value of the diameter relative to the small flange, this is possible through the use of the following system.
Through iteration, by entering different values of $f_{fl}$, the minimum value is identified which allows to contain a wire rope with a length of 2030 m (half of the total length of the wire rope). Going to consider the cases in which there are 12, 11 and 10 layers, the results obtained are reported in table 2.

Table 2. Flange diameters reduced as a function of the number of layers.

| Layers | W [mm] | $\phi_{fl}$ [mm] | $\phi_{fl}$ reduced [mm] |
|--------|--------|-------------------|-------------------------|
| 12     | 4095   | 5173              | 4150                    |
| 11     | 4615   | 4932              | 3900                    |
| 10     | 5265   | 4694              | 3660                    |

Considering that, the height of the platform of a generic trailer varies from 850mm to 1200mm, the solution has been adopted which provides 10 layers of wire rope on the reel. Thanks to this it is possible to obtain a reel of reduced dimensions during transport as can be seen in figure 5.

The complete reel therefore has the following dimensions:

- $\phi_{d} = 1910$ mm;
- $\phi_{fl} = 4700$ mm;
- $W = 5270$ mm;
- $c = 92$ mm;
- $\phi_{fl\text{reduced}} = 3660$ mm.

The reduction of the flange size (from 4700mm to 3660mm) is possible thanks to the decomposition of the same as can be seen in figure 5.

5. Structural sizing of the reel

In addition to problems related to instability [8] [9] [10], the reel is subject to different loading conditions that essentially derive from the way the reel is used/positioned during the transport phases by road and by ship. The different loading conditions are shown in figure 6 they refer to the conditions of transport and handling of the reel, obviously the analyzes were carried out considering all the actions acting on the structure or the own weight and also the various dynamic coefficients induced by the handling of the load [11] [12] [13] [14]. The safety coefficient with which the structure was designed is approximately 10 by adopting S275 UNI EN 10025-2 steel whose main characteristics are: breaking load 430-580MPa and yield strength 275MPa. This fairly high value is justified by the high stiffness that the structure must have both on the drum and on the flanges. The pressure of the wire rope acting on the drum and on the flanges must not induce high values in the elongations and/or bends in order to avoid incorrect winding of the wire rope.
Figure 6. Load conditions diagram to which the reel is subjected (a) resting on the ground; b) lifting the reel with wire ropes; c) vertical support.

Figure 7 shows the results of the finite element analyzes carried out on the reel only for the load conditions identified in the figure 7, a more correct evaluation would be possible by carrying out experimental tests in the field such as [15].

![Figure 7. Results of finite element analyzes for the conditions defined in figure 7.](image)

6. Realization of the reel, and winding it
Figure 8 shows a step during the construction of the reel as well as the winding phases of the wire rope [16]. After winding the wire rope just made on the main reel on the production site, we move on to the partial unloading of the main reel to start winding the wire rope on the auxiliary reel, through the use of specially designed equipment, as can be seen from figure 9.
In particular, the motorized winder/unwinder (currently not available for the capacity indicated), is composed of a stand support that can be modified from winder to unwinder or vice versa through a minimum number of modifications, this system is equipped with a motor to 2.2 kW. It should be remembered that between the two reels there must be a free wire rope length in order to allow the necessary movements between the two vehicles used for transport. Once the unwinding and winding phases have been completed, the two reels will appear as in figure 10 where they are partially full and free of circular segments in order to reduce transport dimensions.

Thanks to the removal of the circular sectors from the two reels, it is possible to obtain a reduction in space, maximizing the maximum occupation of the volume in the loading area of the trailer. Furthermore, considering the minimum height of the subways and overpasses of 5m, it is sufficient to have trailers with a maximum height of the loading platform of less than 1140 mm available, so as to maintain a distance from the overpass of 200mm. If the classic solution had been adopted, the reel would have had a diameter of 4700m and a weight of about 400 tons and the transport would have taken place with a 300/400 tons truss trolley of figure 1 (b), (it is the trailer conventionally used for the
transport of large reels of wire rope, it usually has a length of 60 m). As mentioned in chapter 2, this solution was not absolutely viable as this type of trailer allows to solve the problem of the height of the load, but it increases its longitudinal dimensions and the turning radius, effectively preventing circulation on the roads. For the transport it was therefore decided to adopt the solution (a) of figure 2, for this purpose two trucks equipped with 200-ton trailers are therefore necessary. In choosing the trailer, several table 3 solutions were considered, and then decided to use the trailer N3.0-3 produced by the Titan company (titantrailers.com), whose main dimensions are shown in figure 11.

### Table 3. Trailers dimensions.

| Type   | Width [mm] | Wheelbase [mm] | Height Platform [mm] | Height Minima [mm] |
|--------|------------|----------------|----------------------|-------------------|
| N3.0-1 | 2990       | 1550           | 1070±300             | 770               |
| N3.4   | 3400       | 1600           | 1070±210             | 860               |
| N3.0-2 | 2990       | 1550           | 1080±325             | 755               |
| G3.0   | 3000       | 1500           | 1175±300             | 875               |
| N3.0-3 | 2990       | 1550           | 1070±300             | 770               |

*Figure 11. Main dimensions of the trailer under consideration.*

If we consider the dimensions of the reels transported, the overall dimensions are given by:
- overall height: 3660mm;
- overall width: 3660mm;
- length: 6200 mm occupied by the reel on the trailer, the remaining space on the trailer can be used by additional equipment.

### Table 4. Dimensions and weights of the various parts transported.

| n°  | Part                     | Weight [kN] |
|-----|--------------------------|-------------|
| 1   | Drum                     | 43.25       |
| 2   | Drum square frame        | 122.18      |
| 3,4,5 | Sectors of the flange    | 14.34       |
| 6   | Flange                   | 57.36       |
| 7   | Reel                     | 236.91      |
| 8   | Winder                   | 85.02       |
| 9   | Unwinder                 | 80.54       |
| 10  | Saddle                   | 55.43       |
| 11  | Wire rope guide system   | 15.16       |
|     | Total structure to transport | 749.20     |

*Figure 12. Components to be transported.*

The two trucks must also be rigidly connected to each other, this connection is defined as a rudder, this to prevent the wire rope from being subject to unwanted pulls during transport. In addition, to keep the wire rope in the correct position and avoid excessive movements and oscillations, the cabin of the second truck can be equipped with a support system capable of supporting and guiding the wire rope, allowing only the longitudinal movements necessary to face the curves during the journey. In
addition to the reels on the trailers, as previously highlighted, there is also the system for winding and unwinding the reels. Table 4 and figure 13 show the elements to be transported with the relative dimensions and weights. Once at the destination it will be possible to unload the reels and rewind the reel on a single reel after the related circular sectors have been installed.

7. Conclusions
With this work an innovative system was presented to solve the problems related to the transport of reels for large wire ropes. The innovative solution of adopting two vehicles and a decomposable reel is the only one that has allowed the transport of a wire rope with a diameter of 125 mm and a weight of 400000 kg. If we had not chosen this system, a smaller wire rope would have had to be used, which would have involved, in this case, lifting the load with several sections of wire rope, the presence of winches, their control, etc., considerably increasing handling costs. In this case, the costs for both construction and transportation would have increased. With the proposed solution, which was then implemented, advantages have been obtained linked to the fact that transport presents fewer problems, above all relating to traffic, traffic on the route and the benefits it can bring to the road surface [17] [18] [19], without considering the greater ease of finding suitable vehicle for transport. This system can be convenient if compared with the current available solutions (not feasible for this situation which presents a wire rope of considerable size and length). The transport system studied, which can be generalized by considering more "light" vehicles bound for the transport of wire ropes, could allow a reduction in the cost of transporting goods up to a third of the initial value, even in the face of an investment for the construction of the reels and the winding system (elements that can obviously be reused for subsequent transport and therefore depreciated over time thus guaranteeing greater savings) [20] [21]. For these reasons, the study conducted presents an innovative, efficient and economic solution to traditional transport systems or impossible as regards coils for large wire ropes, trying not to overstress the road surface [22]. Research is still under development by studying a system consisting of several reels designed to transport a single wire rope of large size and length, which is currently not specifically made for problems related to transportation.

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