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Investigation of the Effects of Tensile Force on the Stripping Process in Crane Drum-Rope Mechanisms

Aydoğan Akça*[a], Ece Karslı[b], Engin Tekin[c], Hasan Öktem[d]

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[a,*] KM Kumsan Crane System Company, Dept. of Research and Development, Mechatronic Technician
41455 - Kocaeli, Türkiye
Orcid: 0009-0000-3479-5719
e mail: aydoganakca40@hotmail.com

[b] KM Kumsan Crane System Company, Dept. of Research and Development, R&D Engineer
41455 - Kocaeli, Türkiye
Orcid: 0009-0000-8034-5292

[c] KM Kumsan Crane System Company, Technical Manager
41455 - Kocaeli, Türkiye
Orcid: 0009-0007-1944-7135

[d] Kocaeli University, Hereke Asım Kocabıyık, Dept. of Machine and Metal Technology, Polymer Science and Technology
41800 - Kocaeli, Türkiye
Orcid: 0000-0003-2526-8364

*Corresponding author: aydoganakca40@hotmail.com

ABSTRACT

One of the most important problems is the stripping of the rope, which is a part of the drum-rope mechanisms required in the weight lifting operations used in today's crane systems, from the drum rope clamps under load. This article is a new study in the literature. In this study, the focus is on investigating the design and process parameters of the drum rope clamps used on the drum mechanisms in overhead cranes, simplifying and improving the production. In order to fulfil this objective, firstly, a prototype table-top experimental system that constructs a drum-rope connection has been established. In the experimental study, flat and radius clamps were used as design parameters and the squeezing forces of the bolts connecting the clamps to the drum were considered as process parameters. The tensile force to be applied throughout the study was obtained by making various mathematical calculations. Finally, it was concluded that design and process parameters have significant effects on crane drum-rope systems and comparisons were made on drum rope clamp designs. In addition, it is seen from the experimental results that it has an impact on cost and operational efficiency.

Vinç Tambur-Halat Mekanizmalarında Çekme Kuvvetinin Sıyrılma İşlemi Üzerindeki Etkilerinin İncelenmesi

ÖZ

Günümüzdeki vinç sistemlerinde kullanılan ağırlık kaldırma işlemlerinde gerekli tambur-halat mekanizmalarının bir parçası olan halatın, yük altında halat sıkma pabuçlarından sıyrılması en önemli problemlerden birisidir. Bu makale literatüre konu olacak yeni bir çalışmadır. Bu çalışmada, tavan vinçlerindeki tambur mekanizmalarında kullanılan halat sıkma pabuçlarının tasarım ve işlem parametrelerinin araştırılması, üretimin basitleştirilmesi ve geliştirilmesi üzerine odaklanılmıştır. Bu amacı yerine getirebilmek için, öncelikle bir tambur-halat bağlantısını kurgulayan prototip masa üstü bir deneysel sistem kurulmuştur. Deneysel çalışmada tasarım parametreleri olarak düz ve radiuslu pabuçlar kullanılırken işlem parametreleri olarak da pabuçların tambur ile olan bağlantısını sağlayan cıvataların sıkma kuvvetleri işleme alınmıştır. Çalışma boyunca uygulanması gereken çekme kuvveti çeşitli matematiksel hesaplamalar yapılarak elde edilmiştir. Sonuç olarak tasarım ve işlem parametrelerinin vinç tambur-halat sistemleri üzerinde önemli etkileri olduğu sonucuna varılmış ve halat sıkma pabucu tasarımlarıyla ilgili karşılaştırmalar yapılmıştır. Ayrıca üretim maliyeti ve verimliliği artırmak için işlem parametrelerinden daha çok tasarım parametrelerinin etkili olduğu elde edilen deneysel sonuçlardan görülmüştür.

Anahtar Kelimeler: Çelik halat, vinç tamburu, tork, yivli plaka, halat sıkma pabucu

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1. Introduction

Cranes are work machines consisting of ropes, chains and pulleys; used for loading, lifting, transporting and unloading heavy loads, machines, materials and goods. Although it is used in many sectors in the industry, it has a usage area beyond manpower in terms of the mechanical advantage it provides. For this reason, cranes are widely used.

A comprehensive literature study has been carried out in order to examine the subject in detail. Cranes have rope drums that increase safety and allow tonnes of weight to be lifted easily [1]. Friction that may occur during the sliding of the rope on the drum is minimized in terms of the grooves opened on the drum surface. Thus, the life of the steel rope is prolonged and operational efficiency is increased [2]. In addition to friction, various methods are used to prevent the rope from peeling off the drum. These are; squeezing with grooved plate, squeezing with ungrooved plate, squeezing with flat wedge bolt, squeezing with inclined wedge, etc. The connection of the rope with the drum is realised by methods [3]. In this study, the clamping method with grooved plate was investigated and tested.

Drum rope clamps (grooved plates) are placed on the drum at certain intervals and fixed by tightening with a specified torque value after taking the holes drilled for drum rope clamps on the drum with bolts as reference. While the bolts used for fixing the drum rope clamps on the drum are tightened with a determined torque value, it is aimed to press the drum rope clamp and the drum together and to prevent the possibility of the drum rope clamp slipping under load [4]. Ernst [5] stated that the reason why there is no need to take precautions against loosening of the bolts is due to the spring function of the rope. In their studies, apart from the two windings tightened to the drum rope clamp, at least two windings on the drum were taken as safety windings. As a result, they stated that the friction force arising from the winding of the rope on the drum carries the load. Chang et al. [6] the problems caused by abrasion in steel wire rope were mentioned. As a result of their study, they observed that the reason for the decrease in the performance of the steel rope is due to abrasion. Chang et al. [7] mentioned that the risk of wear poses a serious threat to service reliability and investigated the tribological behaviour of rope by constructing a test rig. They concluded that surface wear and corrosion affect the performance of the wire rope and the friction coefficient is affected by the rope structure, contact angle and sliding speed.

Ye et al. [8] investigated the properties of marine haulage rope subjected to various stresses by a series of full-scale sheave experimental tests on a specially designed test crane. According to reports revealed that the modified rope was able to induce larger loads than before. Hu et al. [9] the torsional effect and damage accumulated in the rope in the manual rope replacement process were investigated. A special fatigue test apparatus was used to perform the specified tests and tests were carried out with various devices to observe the wear and fracture condition of the steel wire. Onur et al. [10] a theoretical model of the torsional properties of parallel multi-piece rope systems is presented. Then, it is stated that the ropes can be wrapped around each other depending on the combination of applied torque, rope tension, length and spacing between rope pieces. Brandon et al. [11] carried out laboratory tests on two- and four-rope systems and performed torque measurements for rotations between 0 and 360 degrees.

Zhang et al [12] argued that in order to prevent stripping, drum rope clamps (grooved plates) mounted on the drum should be used by connecting to the drum with the technique given in Figure 1. The safety windings on the drum reduce the stripping for the rope force applied on each full winding.

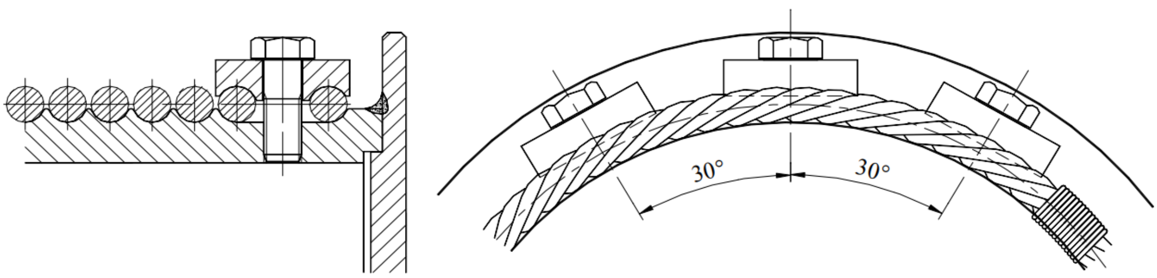

Figure 1. Fastening with grooved plate [3]

In terms of geometrical conformity, it is necessary to manufacture drum rope clamps with different radius values for each variable drum diameter [13]. In this case, it is manufactured by cutting or bending from sheet metal in accordance with the drum diameter from a manufactured pipe that is readily available. In cases where the drum diameter is large or a pipe of suitable diameter is not available, a pipe piece with a suitable radius must be manufactured with cylinder pipe bending machines. This significantly reduces operational efficiency [14]. For this reason, the stripping conditions of the flat rope clamps design, which can be manufactured from an easily available plate that can eliminate such process-consuming and cost-increasing operations, were examined and compared with the currently used rope clamps. Table 1 lists the advantages and disadvantages of the radius rope clamp and the flat rope clamp.

Table 1. Advantages and disadvantages of rope clamps

Radius Rope Clamp	Flat Rope Clamp
It corresponds exactly to the round shape of the drum and therefore provides a tight grip on the rope.	Because it is flat, it contacts a round drum tangentially and the rope squeezing performance may be weaker because it contacts at one point.
Due to its round structure, it contacts the rope from every point and thus causes less damage to the rope. This extends the life of the rope.	Due to the tangential contact with the surface of the rope, it exerts a higher pressure on the rope surface, which prevents all parts of the rope from being crushed evenly.
It is produced specially for each drum, therefore labour cost is high.	Since it is manufactured by cutting from steel plates, the labour cost is much lower.
Since it has a radius, the steel plate needs to be cut and bent. For this reason, the production time is longer.	Since it is manufactured flat, the production time is very short and therefore increases operational efficiency (mass production possibility, time, equipment used, etc.).

In order to increase operational efficiency, a study will be carried out by making design improvements in grooved plates and deciding to test their suitability.

As a result of the researches, no study on drum rope clamps manufactured from flat plates was found and there was not enough research on the problems encountered in the industry. Although, when detailed market researches were carried out on competitor companies, it was observed that flat rope clamps are generally used in companies operating in the machinery manufacturing sector [15,16]. A review of the literature gives that the number of studies in this field is insufficient and there is still a gap that needs to be filled. For this reason, the focus is on the development of the design and process parameters required for the drum-rope mechanism used in crane systems to lift the desired load without stripping. Throughout the study, an experimental system based on the drum-rope mechanism was established. Subsequently process parameters that give the most effective pulling force and the lowest cost were determined.

Present study emphasises the importance of drum rope clamp design in industrial applications and focuses on innovative solutions to meet operational requirements.

In the studies carried out for this purpose, rope stripping forces were obtained as a result of experiments using two different types of rope clamps using certain parameters and methods. The results from two different rope clamps were evaluated, the rope clamp with high operational efficiency, low cost and the most effective pulling force was determined and its usability was ensured.

2. Experimental work

2.1 Parameters and methods

The torque value applied to the bolts in drum-rope mechanisms is determined according to the standard values given in Table 2. These values are expressed in Kg.m and Nm in terms of how much force the bolts, which are fasteners, will be tightened.

The connection of each rope clamp, which is the test parameter, with the drum was tightened with DIN 933 norm M16 bolts at 100, 140 and 205 Nm respectively using a torque wrench as given in Figure 2.

Table 2. Torque values for bolts and screws

Bolt quality	8.8	
Nominal Diameter (Nominal Dia x Pitch)	**Kg.m.**	**N.m.**
M4 x 0.7	0.3	3
M5 x 0.8	0.61	61
M6 x 1	1.42	13
M7	2.34	23
M8 x 1	3.87	38
M10 x 1	8.56	84
M12 x 1.25	9.23	90.6
M14 x 2	13.76	135
M16 x 2	20.89	205
M18 x 2.5	20.84	283
M20 x 2.5	40.77	400
M22 x 2.5	54.23	532

Figure 2. Torque wrench

2.2. Squeezing Moment and Force

In Table 3, the thread table for normal pitch bolts in TS 61 / DIN 13 norm is given and the dimensions of the M16 bolt used in the applied experiment are highlighted.

Table 3. Metric screw normal thread table

Screw Nominal Diameter (D=d)	Thread Pitch	Screw Thread Diameter		Drill Diameter	Pitch Diameter (d2=D2)	Depth of Thread	
		Crest (d1)	Root (D1)			Crest (h3)	Root (H1)
M1	0,25	0,693	0,729	0,75	0,638	0,153	0,135
M2	0,4	1,509	1,567	1	1,74	0,245	0,217
M3	0,5	2,387	2,459	2,5	2,675	0,307	0,271
M4	0,7	3,141	3,242	3,3	3,545	0,429	0,379
M5	0,8	4,019	4,134	4,2	4,48	0,491	0,443
M6	1	4,773	4,917	5	5,35	0,613	0,541
M8	1,25	6,466	6,647	6,8	7,188	0,767	0,677
M10	1,5	8,16	8,376	8,5	9,026	0,92	0,812
M12	1,75	9,853	10,106	10,2	10,863	1,074	0,947
M14	2	11,546	11,835	12	12,701	1,227	1,083
M16	**2**	**13,546**	**13,835**	**14**	**14,701**	**1,227**	**1,083**
M18	2,5	14,933	15,294	15,5	16,376	1,534	1,353
M20	2,5	16,933	17,294	17,5	18,376	1,534	1,353
M22	2,5	18,933	19,294	19,5	20,376	1,534	1,353

Table 4. Symbols and values table

D2 (Section Diameter)	14.701 mm
P (Screw pitch)	2 mm
μ (Coefficient of Friction)	0.1
α (Thread Angle)	60°
β (Helix Angle for a bolt with M16 and 2mm pitch)	2.48°
ρ (Angle of Friction 0.1 coefficient of friction and 60° for thread angle)	6.586°

The relationship between the tightening moment and the tightening force is calculated as the sum of the moment between the screw threads and the moment created by the nut surface on the material surface according to the formula below.

M_s = Squeezing moment
D_{Nut} = Nut diameter

$$M_s = F_p.\left(\frac{D2}{2}.\tan(\beta + \rho) + \mu.\frac{D_{Nut}}{2}\right)$$

Examination of the torque table for bolts in Table 2 shows that the required tightening torque value for an 8.8 grade bolt in M16 size is 205 Nm.

According to DIN931 standard, the "Screw head" value of the M16 bolt is determined as 24mm is substituted in the formula below according to the squeezing torques of 100, 140 and 205 Nm applied during the test phase;

$$M_{s_{205}} = F_{p_{205}}.\left(\frac{D2}{2}.tan(\beta + \rho) + \mu.\frac{D_{screw\ head} - d_{Hole\ Diameter}}{2}\right)$$

$$\Rightarrow 205.10^3 = F_{p_{205}}.\left(\frac{14.701}{2}.tan(2.48 + 6.586) + 0.1.\frac{24 - 17}{2}\right)$$

$$\Rightarrow F_{p_{205}} = 134.625\ N$$

From here by similar methods;
F_P = Squeezing force
Squeezing force of 100, 140 and 205 Nm torque value;

$F_{p_{100}} = 65.670\ N$

$F_{p_{140}} = 91.939\ N\ and$

$F_{p_{205}} = 134.625\ N$ is found.

2.3 Determination of rope friction force depending on squeezing force

M_s half of the F_P force generated as a result of the squeezing moment (if the bolt hole axis divides the pressure surface of the rope clamp on the drum and the rope pressure surface into two equal distances) is applied to the rope as given in Figure 3. Then, acting on the groove surface opened on the drum and the groove surface on the rope clamp clip. In this case, F_{p_rope} in Figure 4 is applied in the opposite direction to and $F_s = 2.\mu.\frac{F_p}{2}$ friction force is generated. This formula is simplified $F_s = \mu.F_p$ value is found.

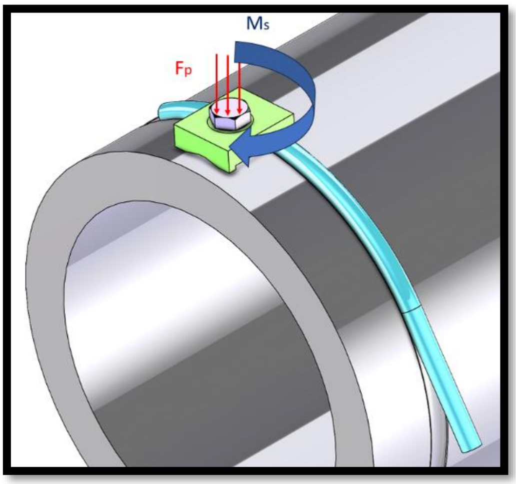

Figure 3. Forces Acting on the Rope I

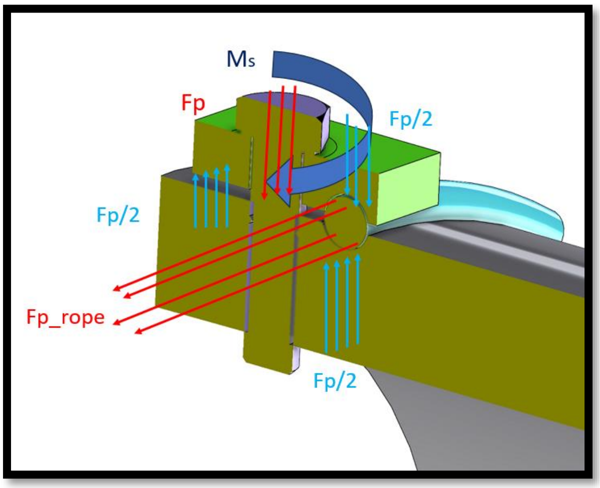

Figure 4. Forces Acting on the Rope II

2.4 Effect of rope winding number on rope pulling force

In this section, three rope clamps were used in standard crane drum. In addition to this, the design is conduct in such a way that as can be seen in Figure 5 at least 3 wrapped grooves remain wrapped around the drum when the hook block is at the lowest point.
In addition, the remaining 3 wound grooves are calculated according to the formula below.

F_{P_rope} = Rope squeezing force

F_{load} = Drum mechanism load

$$F_{p\_rope} = \frac{F_{load}}{e^{\mu.\alpha}} \quad [17]$$

It's here;

e = 2.718 is the natural logarithm number.

μ = Coefficient of friction between the rope and the drum (taken as 0.1 to stay on the safe side)

α = Rope winding angle in radians (6.π is taken for 3 windings)

The load attached to the rope for a drum mechanism with three grooves wound at the extreme end (with the least number of grooves wound on the drum);

$$e^{\mu.\alpha} \Rightarrow e^{0.1.6\pi} \Rightarrow 6.58 \; times\ as\ much\ and$$

It is obvious that a drum mechanism to which 3 rope clamps are connected can hold the load with 6.5x3=19.75 times less force.

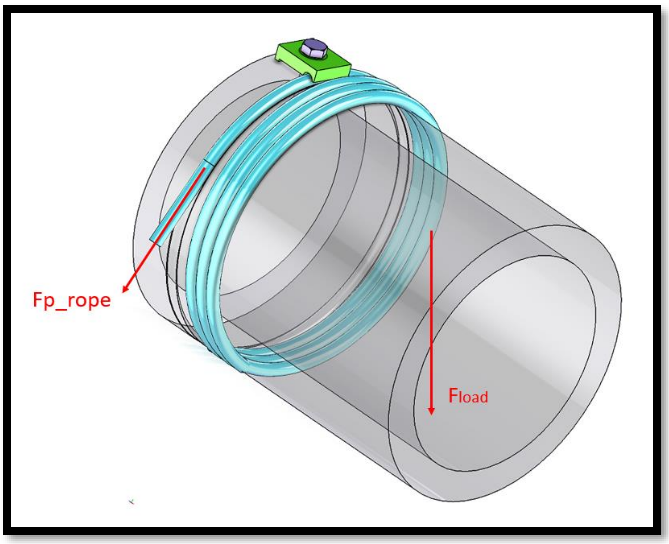

Figure 5. Drum Mechanism

2.5 Test setup (mechanical test)

In drum - rope mechanisms, rope clamps are used to prevent the rope wrapped around the drum from stripping. These rope clamps can be manufactured in two different types. Radius and Flat type clamps have their own advantages and disadvantages. The experimental setup given in Figure 6 was set up in order to determine whether the mentioned rope clamps can be manufactured with the most effective pulling force and the lowest cost in drum - rope mechanisms. By using the experimental setup, the rope stripping forces of the rope clamps manufactured with radius and flat shape will be compared. Thus, after making a comparison according to the results obtained from the experiment, the design with high operational efficiency, low cost and the most effective tensile force value will be determined from the rope clamps to be used in drum - rope mechanisms.

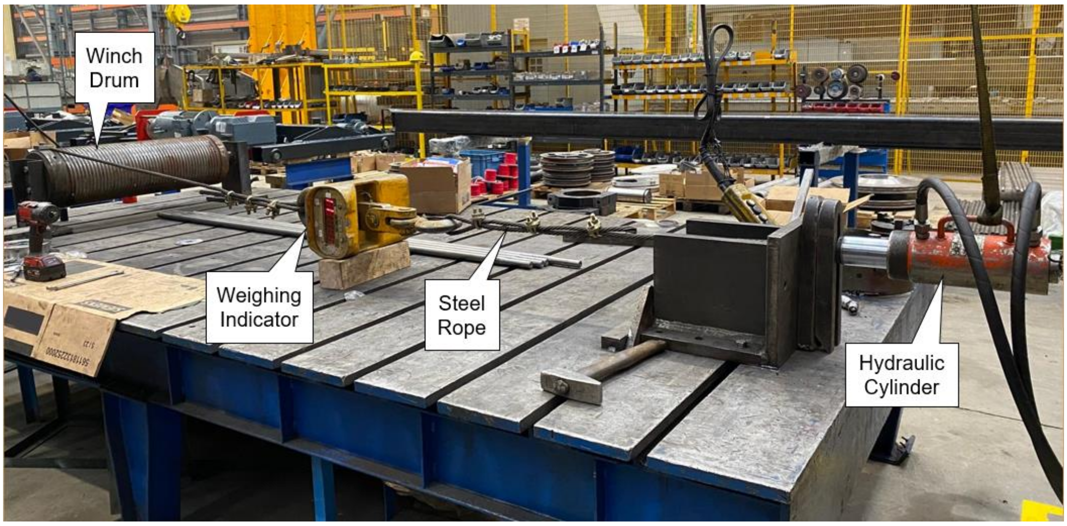

Figure 6. Experimental setup

2.6 Stripping effect of drum rope clamps under tensile force

Rope clamps are used in drum-rope mechanisms to prevent rope stripping. Two different types of rope clamps, flat type and Radius type, were used as test parameters. Figure 7 represents the flat type and Figure 8 represents the Radius type rope clamp. A number of experiments were carried out to determine the rope stripping forces of two different types of rope clamps on the experimental set-up as given in Figure 6. The experiment was first started with the flat type rope clamp given in Figure 7. The flat type rope clamp is connected to the drum with M16 bolt and tightened to 100 Nm using torque wrench. In order to determine the stripping force of the wire rope between the drum and the rope clamp, a hydraulic cylinder was used. Subsequently pulling force was applied to the wire rope with the hydraulic cylinder until the moment of stripping. The stripping force value at the moment that the steel wire rope starts to be stripped from the place where it is clamped to the drum was read from the weighing indicator. The same procedure was applied for torque values of 140 and 205 Nm respectively and the rope stripping forces were obtained.

Afterwards, the number of flat type rope clamp, which were connected to the drum, was increased from 1 to 2. The rope clamps were placed at 30° intervals and their connections with the drum were carried out M16 bolts under the same conditions. Firstly, the rope stripping force was tested with a torque value of 100 Nm applied to the bolts. The same process was applied for 140 and 205 Nm torque values respectively and rope stripping force values were obtained.

For the last test of the flat type rope clamp, the number of clamps was increased from 2 to 3 and the rope clamps were placed at 30° intervals. Under the same conditions, respectively, the bolts were tightened with a torque wrench at 100, 140 and 205 Nm. Then the pulling force was applied by means of a hydraulic cylinder until the steel rope between the drum and the rope clamp was stripped.

As a result of the applied tensile force, rope stripping forces were obtained. The experiments applied for the flat type rope clamp were also applied for the radius type rope clamp indicates in Figure 10 with the same conditions and methods. The results of the experiments are listed in Table 4 and Table 5.

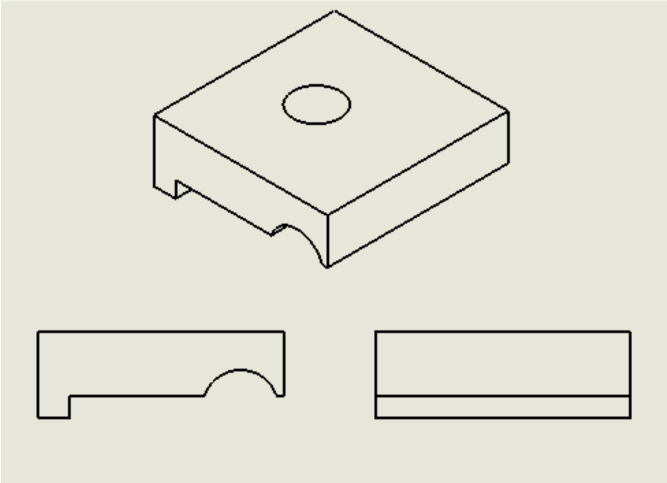

Figure 7. Technical drawing of a flat type drum rope clamp

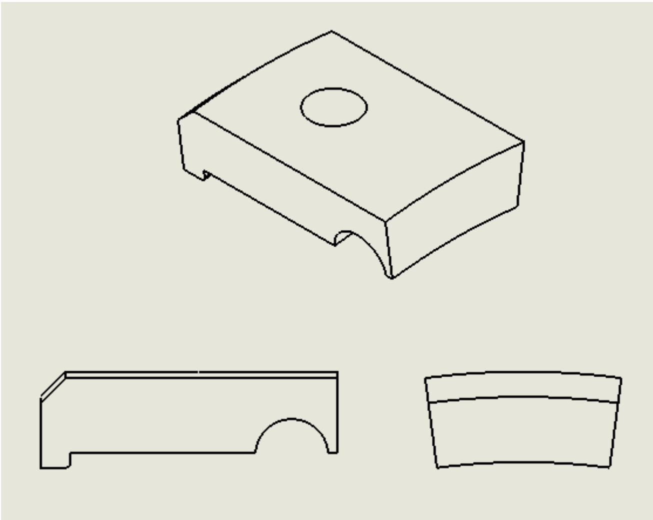

Figure 8. Technical drawing of a radius type drum rope clamp

3. Result and Discussions

In this section, all the results of the rope stripping forces obtained from the tests on the rope clamps are analysed and evaluated. Tables 4 and 5 give the rope stripping forces obtained as a result of the tensile force applied to the steel rope between the rope clamp and the drum. The results obtained from Tables 4 and 5 were interpreted and the graphs given in Figures 9 and 10 were created.

Table 5. Radius type rope clamp

	Number of Clamps	Squeezing Torque (Nm)	Clamp Geometry	Rope Stripping Force (kg)
Test 1	1	100	Radius	250
Test 2	1	140	Radius	500
Test 3	1	205	Radius	800
Test 4	2	100	Radius	700
Test 5	2	140	Radius	1300
Test 6	2	205	Radius	2400
Test 7	3	100	Radius	1900
Test 8	3	140	Radius	2550
Test 9	3	205	Radius	3700

From Table 4, it can be seen, each Radius type rope clamp was fixed to the drum with a clamping torque value of 100, 140 and 205 Nm respectively. After the pulling force was applied to the steel rope between the rope clamp and the drum using a hydraulic cylinder at 100, 140, 205 Nm clamping torque values, the rope stripping forces give in Table 4 were obtained in "kg". Considering the results in Table 4, it is observed that the rope stripping force varies depending on the number of clamps and the squeezing torque value. Using the data in Table 4 and the data obtained from the experimental results, the result graph of the Radius type rope clamp given in Figure 9 was created.

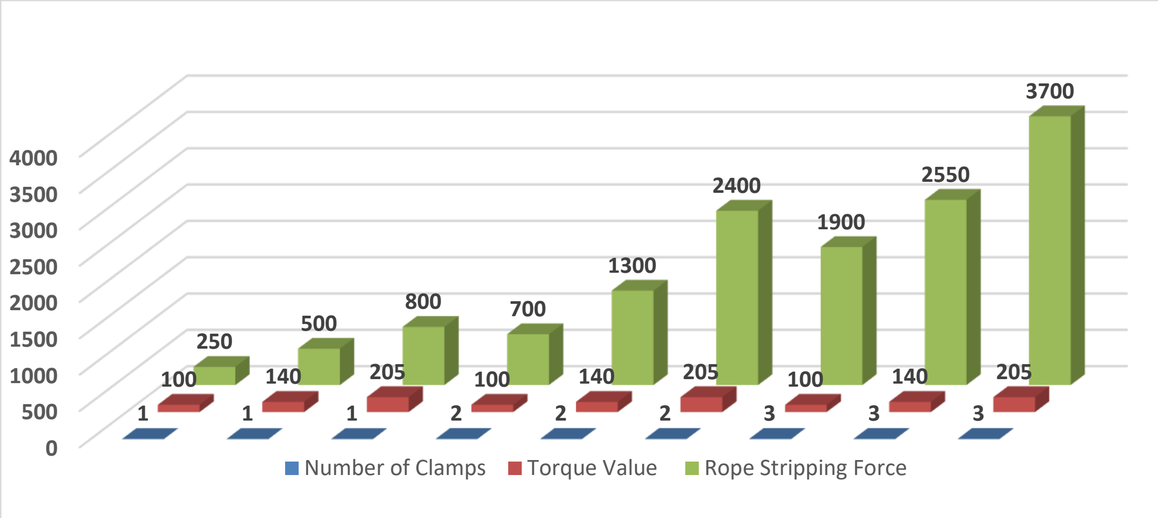

Figure 9. The rope stripping force of radius type rope clamp

The result graph of the Radius type rope clamp is given in Figure 9. As the number of clamps and the tightening torque value increases, the rope stripping forces increase as the steel rope between the drum and the clamp is held more tightly. The rope stripping force obtained when one clamp is fixed to the drum with a torque value of 205 Nm is higher than the rope stripping force obtained when two clamps are fixed to the drum with a torque value of 100 Nm. It is observed that this situation is due to the fact that the radius type rope clamp contacts the drum at every point and grips the steel rope more tightly at high torque value.

Table 6. Flat type rope clamp

	Number of Clamps	Squeezing Torque (Nm)	Clamp Geometry	Rope Stripping Force (kg)
Test 1	1	100	Flat	200
Test 2	1	140	Flat	350
Test 3	1	205	Flat	450
Test 4	2	100	Flat	500
Test 5	2	140	Flat	700
Test 6	2	205	Flat	1600
Test 7	3	100	Flat	1450
Test 8	3	140	Flat	2000
Test 9	3	205	Flat	3100

In Table 5, the results obtained from the experiments performed on the flat type rope clamp under the heading of rope stripping force are given in "kg". Each flat type rope clamp was connected to the drum with M16 bolt with a squeezing torque value of 100, 140 and 205 Nm respectively. A hydraulic cylinder was used to apply a pulling force until the steel rope between the drum and the flat type rope clamp was stripped. The stripping forces obtained are given in Table 5 together with the experimental parameters. The results in Table 5 are considered, it is observed that the rope stripping force varies depending on the number of clamps and the squeezing torque value. Using the data in Table 5 and the data obtained from the experimental results, the result graph of the flat type rope clamp given in Figure 10 was created.

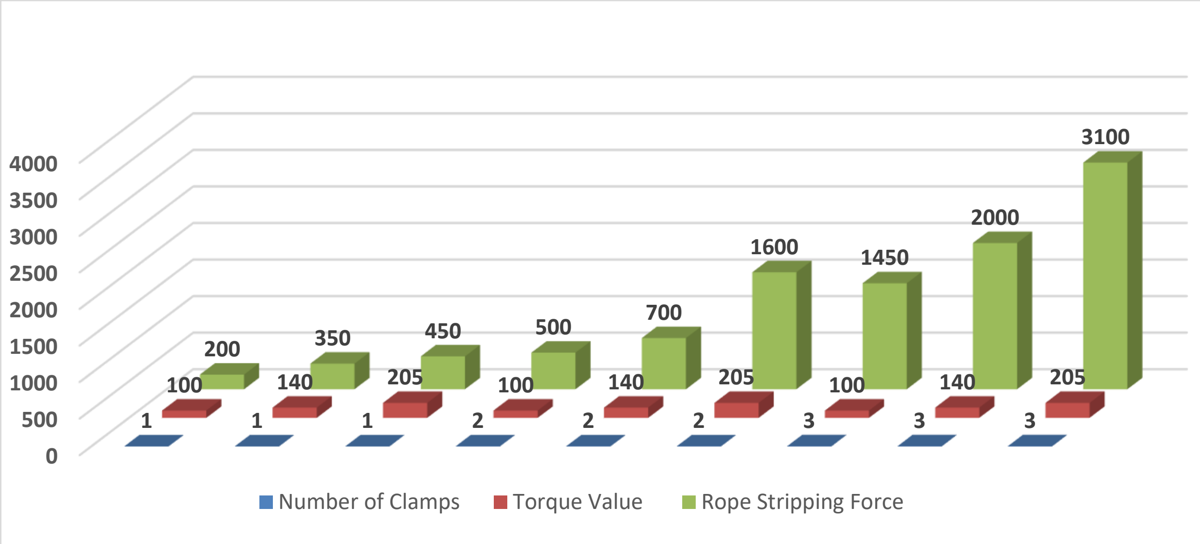

Figure 10. The rope stripping force of flat type rope clamp

Analysing the result graph of the flat type rope clamp in Figure 10, since the flat type rope clamp applies pressure from a tangent point to the drum, the rope stripping force value also increases with increasing the number of clamps. In addition to increasing the number of clamps, it was observed that the stripping force of the steel rope between the drum and the clamp also increased with the increase in torque values. Thus, according to the result graph of the flat type rope clamp given in Figure 10, it is observed that the rope stripping force increases in direct proportion to the number of clamps and torque value.

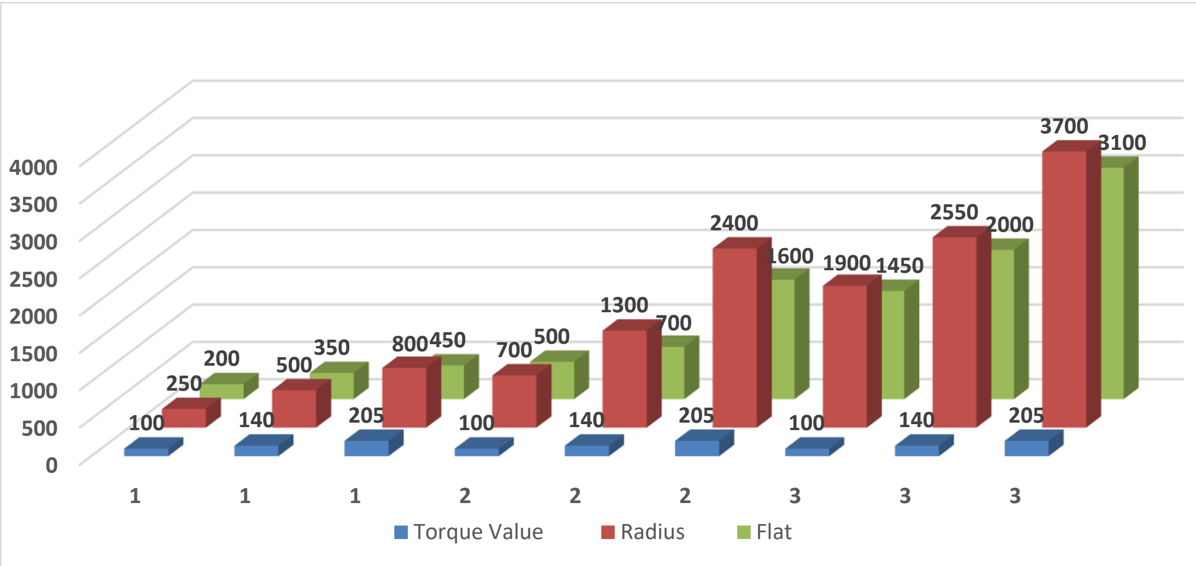

Figure 11. Comparison of radius and flat type rope clamps

Depending on the varying number of clamps and torque force, the rope stripping forces of two different types of rope clamps were tested under each condition. Figure 11 represents the comparison graph of the radius and flat type rope clamps. From Figure 11, it is seen that under the same conditions, the radius type rope clamp holds the steel rope more tightly and the stripping force is higher than the flat type rope clamp. It is determined that this situation is due to the fact that the radius type rope clamp contacts the drum at every point, while the flat type rope clamp contacts the drum at a single point.

4. Conclusion

This paper focused on the effect of the design of the rope stripping forces obtained as a result of the tensile force applied to the rope clamps, which prevent the stripping of steel ropes, under variable clamp number and torque values, were investigated by means of experiments. The results obtained from these experiments and the conclusions reached in the light of the evaluations can be summarised as follows:

- Radius type rope clamp has approximately 20% more rope stripping force than flat type rope clamp.
- Radius rope clamp has high production cost and low operational efficiency (mass production possibility, time, equipment used, etc.). Flat type rope clamp is more advantageous in terms of cost and efficiency.
- In drum rope connections, it has been determined that the most effective rope clamp in terms of cost, standardisation and mass production is the flat type rope clamp, since 3 winding grooves are generally left as safety grooves.
- The rope clamps counterbalance a 5 tonne rope load with a load 19.75 times less in the three safety grooves. This provided a smooth load carrying for the flat type rope clamp. Thus, the manufacturing difficulties, costs and time losses of the radius type rope clamp are eliminated.
- As a result of the research, it was seen that this study is a new topic in the literature. There is no study on the clamps mounted on the drum.

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Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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