SEPTEMBER 2015
www.craneworld.com
A KHL Group publication

INTERNATIONAL cranes AND SPECIALIZED TRANSPORT

Middle East

Ropes and winches

Financing

IC Tower Index

Tower cranes

TopLift

Overhead record

S&RA
OFFICIAL MAGAZINE

SPECIALIZED TRANSPORT, TOWER CRANE SITE REPORT, THE KNOWLEDGE

Advanced advantage

This month MARCO VAN DAAL goes deeper into the principle of mechanical advantage using different pulley systems

We begin this article by referring back to three figures from last month's article. These are Figures 1, 2 and 3.

Last month we saw that the red line that cut the parts of line was an indication for the mechanical advantage of the pulley arrangement.

ABOUT THE AUTHOR

Marco van Daal has been in the heavy lift and transport industry since 1993. He started at Mammoet Transport from the Netherlands and later with Fagioli PSC from Italy, both leading companies in the industry. His 20-year plus experience extends to five continents and more than 55 countries. It resulted in a book *The Art of Heavy Transport*, available at: www.khl-infostore.com/books Van Daal has a real passion for sharing knowledge and experience and holds seminars around the world.

We will now analyse each of these three arrangements and determine the load at the anchor point, the point on which the entire pulley system is suspended.

For this exercise we disregard the angle at which the hoist line departs from the top sheave.

FIGURE 1:
This pulley arrangement had a mechanical advantage (M.A.) of 1. The line pull (L.P.) in this case is equal to the load being lifted (F_L = 100 Newton).

The load in the anchor point (F_A) is therefore F_A = L.P. + F_L = 100 Newton + 100 Newton = 200 Newton.

FIGURE 2:
This pulley arrangement had a mechanical advantage (M.A.) of 2. The line pull (L.P.) in this case is equal to the load being lifted (F_L = 50 Newton). The load in the anchor point (F_A) is therefore F_A = L.P. + F_L = 50 Newton + 100 Newton = 150 Newton.

FIGURE 3:
This pulley arrangement had a mechanical advantage (M.A.) of 3. The line pull (L.P.) in this case is equal to the load being lifted (F_L = 33.3 Newton).

The load in the anchor point (F_A) is therefore F_A = L.P. + F_L = 33.3 Newton + 100 Newton = 133.3 Newton.

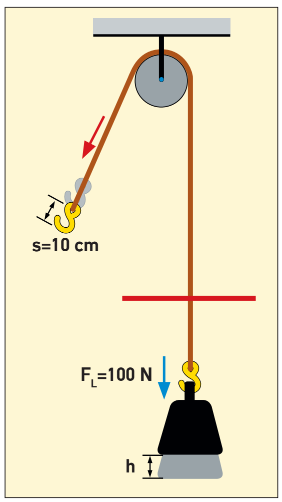

FIGURE 1

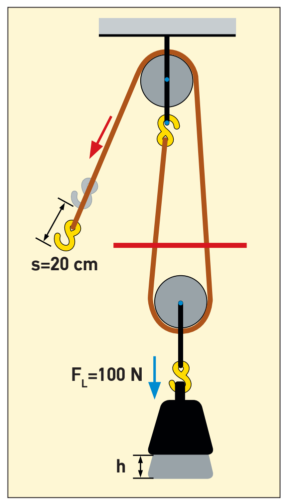

FIGURE 2

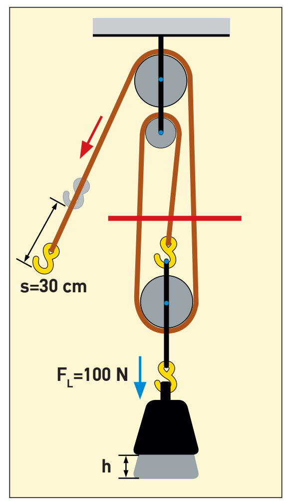

FIGURE 3

The conclusion we can draw from this is that the anchor point can be of a lesser capacity as the number of line parts increases. Why is this important in our heavy lift industry?

To answer this question, consider the following scenario:

A crane has a charted capacity of 10 ton at 12 metres (40 feet). The maximum line pull for this crane is 12 ton, the hoist rope is of the same capacity, as is the headache ball.

It is the intention to lift an 8 ton load (this includes the hook block and rigging) at a radius of 12 m (40 feet), this is well within the capacity of the crane. As a matter of fact the crane can perform this lift and still have a 20 % safety margin.

The crane chart shows a note stating: "for loads over 5 ton and over 6 m (20 feet) use at least a double sheave block with four parts of line".

Let's analyse the following scenarios:

A.) lifting the 8 ton load (F_L) with the headache ball on a single part of line.

B.) lifting the 8 ton load (F_L) with a single sheave black on two parts of line.

C.) lifting the 8 ton load (F_L) with a double sheave black on four parts of line.

Lifting the load with the headache ball

The mechanical advantage (M.A.) is 1. The required line pull equals the load to be lifted which is 8 ton. The load in the anchor (F_A), which in this case is the boom tip, is F_A = L.P. + F_L = 8 ton + 8 ton = 16 ton.

The crane chart however states the crane is only suitable for 10 ton at this radius. By reeving the crane with only a headache ball an overload scenario has been created.

Lifting the load with a single sheave block

The mechanical advantage (M.A.) is 2. The required line pull equals the load to be lifted which is 4 ton. The load in the anchor (F_A), which in this case is the boom tip, is F_A = L.P. + F_L = 4 ton + 8 ton = 12 ton.

The crane chart however states the crane is only suitable for 10 ton at this radius.

By reeving the crane with a single sheave block an overload scenario has been created.

Lifting the load with a double sheave block

The mechanical advantage (M.A.) is 4. The required line pull equals the load to be lifted which is 2 ton. The load in the anchor (F_A), which in this case is the boom tip, is F_A = L.P. + F_L = 2 ton + 8 ton = 10 ton.

This is exactly the capacity shown in the chart. By reeving the crane with a double sheave block a safe lift scenario has been created.

IMPORTANT NOTES

The above example is to show how the forces in the anchor point, the boom tip, decrease as more parts of line are being used. In practice it is not necessary to perform this calculation, the charts for each crane are developed taking the line pull into account. The chart capacity is the real lift capacity.

It is just to clarify that charts are developed in a way that produces the highest lifting capacity in each scenario.

In some cases this result in a requirement to reeve a hook block with more parts of line than what would seem necessary at first glance.

Simple, compound and complex pulley systems

The pulley arrangements in Figures 1, 2 and 3 are called simple pulley systems. To qualify for this title, it needs to satisfy the following two criteria.

1.) all moving pulleys need to move towards the anchor

2.) all moving pulleys need to move towards the anchor at the same speed.

Once this is confirmed, the mechanical advantage can be determined by counting the number of parts of line that supports the load. See the calculations or last month's article to confirm this statement. The principle of counting parts of line can only be applied to a simple pulley system.

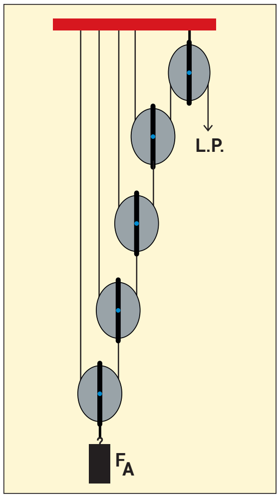

FIGURE 4

Compound pulley system

Review the five pulley system in **Figure 4**. We need to determine if this is a simple pulley system. If it is we can count the number of parts of line to determine the mechanical advantage.

DEFINITION 1; "all moving pulleys need to move towards the anchor". This pulley system complies with this first requirement, as we pull down on L.P. (Line Pull) the load will raise off the ground and all pulleys will move towards the anchor.

Note, we can disregard pulley 1 as this pulley does not contribute to any mechanical advantage, it merely changes the direction of the L.P. from a downward to an upward direction.

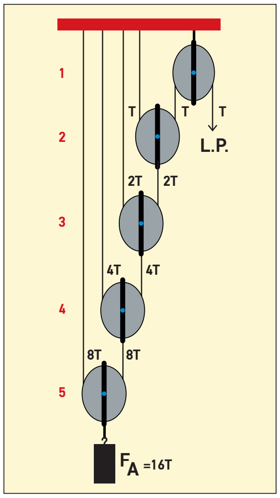

FIGURE 5

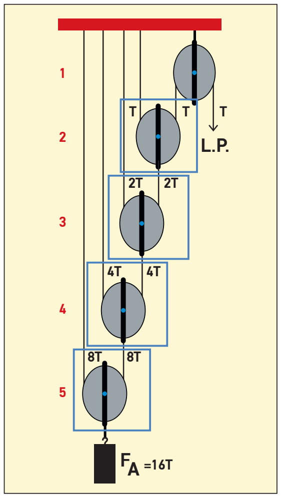

FIGURE 6

DEFINITION 2; "all moving pulleys need to move towards the anchor at the same speed"

We can determine this by using the T-method. T standing for tension. Review **Figure 5**. When pulling down on the L.P. we introduce a tension T in the rope, this tension will remain as the rope runs over pulley 1 and also remains as it approaches and departs from pulley 2 and terminates at the anchor (in red).

Pulley 2, however, experiences a load T on each side and consequently it can lift a weight equal to 2*T=2T. Therefore the mechanical advantage of pulley 2 is 2.

The tension (2T) in the rope attached to pulley 2 remains as it approaches and departs from pulley 3 and terminates at the anchor (in red). Pulley 3 experiences a load 2T on each side and consequently it can lift a weight equal to 4T. The mechanical advantage of pulley 3 is 2.

At this point we can make a statement. Pulley 2, by itself a simple pulley system, will move up at half the distance that L.P. moves down. Pulley 3, by itself also a simple pulley system, will move up at half the distance that pulley 2 moves up. Therefore pulley 3 moves up at one quarter of the distance that L.P. moves down.

CONCLUSION 1: Pulley 2 and pulley 3 do not move up at the same speed. Therefore this arrangement is not a simple pulley system (see definition 2 of a simple pulley system) and the mechanical advantage (M.A.) may not be determined by counting parts of line.

CONCLUSION 2: Each of the pulleys (with the exception of pulley 1) are by themselves simple pulley systems so this arrangement is called a compound pulley system. The definition of a compound pulley system is that it is built up from multiple simple pulley systems attached to each other.

Back to Figure 5, continuing the T-method as applied to pulley 2 and 3 above, pulley 4 can lift a weight equal to 8T and pulley 5 can lift a weight equal to 16T. With a line pull of 1T a load of 16T can be lifted. The mechanical advantage is 16. As you can see there are not 16 parts of line that could have been counted.

There is however an alternative and easier way to determine the mechanical advantage by isolating each of the simple pulley systems and determining the mechanical advantage per simple pulley system. See **Figure 6**. Each of the blue squares contains a simple pulley system and each of these has a mechanical advantage of 2. Check this for yourself. Note that the mechanical advantage of pulley 1 is 1 as it only changes the direction of the force.

The mechanical advantage of the compound pulley system is the multiplication of each of the simple pulley systems. M.A.1. * M.A.2. * M.A.3. * M.A.4. * M.A. 5 = 1 * 2 * 2 * 2 * 2 = 16.

As seen last month, a mechanical advantage of 16 has to be at the cost of another property to "balance" the system due to the law of conservation of energy. You will need 16 times the amount of rope at L.P. to lift the load a foot (or a metre) off the ground.

Complex pulley system

A complex pulley system is any pulley system that is not a simple or compound pulley system. There is no one definition that characterises all complex pulley systems. With only four pulleys almost 100 different complex pulley systems can be made.

Due to their complexity, the complex pulley systems are not used frequently as they are also mostly impractical. It is not always easy and straightforward to determine if a pulley system is a compound pulley system or a complex pulley system.

The mechanical advantage of complex pulley systems can be determined in two ways. The most practical way is the T-method as outlined above.

For systems that become too complex to use the T-method, as pulleys may move in opposite directions, is to build the complex pulley system (field test) and pull a rope a known distance at the Line Pull end and measure the distance that the load was raised. The ratio is the mechanical advantage.

Review **Figure 7**. This is a complex pulley system, as the top pulley is connected to both the second and the third pulley. The mechanical advantage can no longer be determined by counting the parts of line nor by isolating each pulley and multiplying the individual mechanical advantages.

The mechanical advantage for this system can only be determined by the T-method or by field testing.

Figure 8 shows the results of the T-method, check this for yourself.

A quick method to check the correctness of the various loads. The total load in the anchor point (the red bar) should be equal to the load to be lifted (F_A) plus the line pull (L.P.), both are 5T which means that the forces are correct.

Food for thought: pulley 1 is stationary, pulley 2 moves downwards, pulley 3 moves upwards. ■

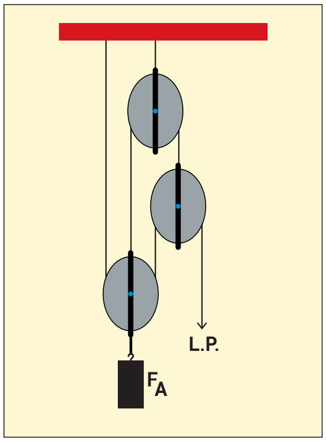

FIGURE 7

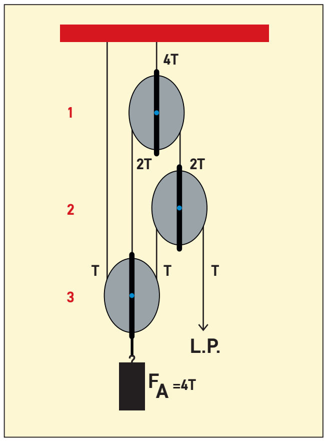

FIGURE 8