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# Specification, design, and simulation of mechanical horses following the opinion of Khong Minh in the novel "Three Kingdoms"

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***ABSTRACT***

*This article presents how to speculate, design and simulate a mechanical horse based on the point of view of the military man Khong Minh, a talented character in the work "Three Kingdoms" (author La Quan Trung). The behavior of this type of horse closely resembles that of a real horse. That is, it can walk, run, carry goods or people. It is made mainly of wood or steel. The authors speculated that Khong Minh placed a leaf spring in the belly of the mechanical horse. Soldiers just need to rotate so that the leaf spring twists, it will store energy in the form of potential energy. Then, it slowly unfolds, and the potential energy is converted into kinetic energy, transmitting motion to the mechanisms connected to the horse's legs. Finally, the mechanical horse lifted his leg and was able to walk. Despite such speculation, when recreating a mechanical horse, our team of authors used a battery-powered motor instead of leaf springs and gear transmissions as a pre-assembled transmission part in the belly of the mechanical horse. We design additional parts such as the head, tail, belly, legs, etc. to create a complete mechanical horse. The design goal of the author's mechanical horse is to clear people's doubts about the "wooden buffalo mechanical horse" in the literary work "Three Kingdoms". At the same time, this type of mechanical horse is also applied as an amusement ride for people in tourist areas and as a children's toy in the family.*

***Keywords:*** ***c****hildren's game, four-legged robot, simulation, "wooden buffalo mechanical horse", design*

## 1. Introduction

Perhaps, many people have read the story or watched the movie "Three Kingdoms" and surely everyone wondered about the miracle of the “Wooden buffalo mechanical horse” in that work. The authors of this article, too, wondered how Khong Minh could design a mechanical horse that carried food all day and night through the mountains! At that time, around AD 230, people still used rudimentary tools, there wasn't any machinery for Khong Minh to create a mechanical horse that could go so far and for so long. Even today, people have modern machines that they can't even make such a mechanical horse. Because of doubt and curiosity, we wrote this article, speculated, and designed a mechanical horse in the way of Khong Minh. However, our mechanical horse cannot walk on its own and requires an electric motor and other actuators.

In order for readers to know more about mechanical horses as described by Khong Minh, we quote a passage from "Three Kingdoms" as follows:

*“One day, Duong Nghi came in and said: Currently, rice is stored in the Kiem Cac mountain, farmers and buffaloes and horses are very hard to transport, what to do?*

*Khong Minh laughed and said: I think it's been a long time! Previously, we had stored timber and also bought big timber in Tay Xuyen. I sent someone to build wooden buffaloes and mechanical horses to transport rice, which is very convenient. The wooden buffaloes and mechanical horses do not have to eat or drink anything and can go all day and night.*

*The generals were surprised and asked: From ancient times to now, no horse has ever run. What kind of magic does the prime minister have to create such a strange machine?*

*Khong Minh said: I sent someone to make it, but it's not done yet. Now I tell you how to be square, wide, narrow, long, and short, let you see them.*

*After listening, the generals were very happy. Khong Minh wrote down a piece of paper and showed it to them. The generals finished watching, rejoiced, and said: The prime minister is really a god!*

*After a few more days, the wooden buffaloes and mechanical horses will be finished, just like real buffaloes and horses, can go up and down the mountain. When the three soldiers saw it, they clapped their hands and cheered."*

*“Sam Uy rode on his horse and fought again, was killed by Vuong Binh, the Wei army ran away, and Vuong Binh immediately sent his army to lead the wooden buffaloes and mechanical horses. The Wei army returned to the Northern Yuan camp to report the news. Quach Hoai hastily led the army to rescue. Vuong Binh ordered his army to pull out the horse's tongues, leave them all along the road, and then beat and run. Quach Hoai ordered the army not to chase, but to bring the wooden buffaloes and mechanical horses. But when the soldiers pulled the whole thing and led the horse and buffalo away, the shaking couldn't move, the pulling couldn't move. Quach Hoai was skeptical and didn't know why. Suddenly, drums beat, horns blow, and shouts from four sides, then two armies*

*of Nguy Dien and Khuong Duy came over. Vuong Binh also turned around, and three faces attacked. Quach Hoai was defeated and ran away. Vuong Binh sent troops to put the horse's tongue in and then urged them to pull it away. When Quach Hoai saw this, he tried to turn around and chase after him. Suddenly, behind the mountain, there was a thick black smoke rising up, and then a team of gods pulled out, each holding a flag, a sword, and a strange face, gathered around and led the team of wooden buffaloes and mechanical horses away, fast like the wind".*

*Excerpted from "Three Kingdoms", vol. 102 (Translated by Phan Ke Binh, edited by Bui Ky)*

Through the above excerpt, we see that Khong Minh's "Wooden buffalo mechanical horse" is very unique. They can go day and night. Attach their tongues and they go as fast as the wind, remove them and they stay still, soldiers cannot move them. It is also for this reason that when the Tu Ma Y army stole two mechanical horses from the Khong Minh army, they made more than 2,000 similar ones, but they could not control them to go as they wanted. That trick is right on the tongue of the mechanical horse!

Obviously, at that time, the invention of the "Wooden buffalo mechanical horse" made Khong Minh a great scientist, educator, and military man in China. Thanks to his scientific talent and expertise in geography, he won many battles. The generals wholeheartedly praised him, considering him a god. The enemy side was also very impressed and bewildered by his miraculous invention.

Today, Khong Minh's initiative "Wooden buffalo mechanical horse" has been lost, no one knows about that product anymore. Many people wonder if Khong Minh made a real "Wooden buffalo mechanical horse" or a fictional La Quan Trung. Because there can't be a permanent engine, a "Wooden buffalo mechanical horse" carrying food day and night through the mountains and forests is absurd. However, with the talent of Khong Minh, it is highly likely that he has made the "Wooden buffalo mechanical horse" according to some secret, which has made the readers of the story "Three Kingdoms" half doubt, truth and confusion, confused! Could it be that the "Wooden buffalo mechanical horse" Really, but because of the war, military secrets were not revealed, leading to the disappearance of those four-legged machines.

We must also admit that scientific knowledge is endless. Humans only know a little of the laws of nature and pass them on to others to use, and a huge part of the knowledge is unknown to humans. Even, the superior knowledge created by the ancient cardinals, but without a successor, has been lost (There are many documents that say that the thought at that time was not to pass the secret to the unworthy). The same goes for the "Wooden buffalo mechanical horse" problem. If it's real, it's also lost due to a lack of successors! The group of authors we imagine is a descendant of Khong Minh, trying to recreate that mythical animal.

Horses are gentle livestock, handy to humans. Cherishing horses, humans have created mechanical horses with many good uses. The wooden horse is a fun and kid-friendly game around the world. A wooden horse with a machine inside is a great invention of man.

*a) b) c)*

*a) Lu Ban's mechanical wooden carriage (FC Chen et al., 2012)*
*b) Lu Ban's machine horse foot transmission structure (Hong-Sen Yan, 2013)*
*c) Lu Ban's horse-drawn carriage carries people (Hong-Sen Yan, 2013)*

**Figure 1.** The earliest tractor-drawn horse was designed by Lu Ban

Some studies have included: Lu Ban's mechanical horse as shown in figure 1 (circa 450 BC, FC Chen et al. (2012)); Khong Minh's mechanical horse (circa 230 AD, lost or only created by author La Quan Trung to make the novel "Three Kingdoms" more attractive). Lu Ban is considered the forefather of the construction industry. He created a lot of work tools. Author FC Chen et al. (2012) assume that the mechanical horse shown in Figure 1 belongs to Lu Ban in the article *"On the Motion of a reconstructed ancient Chinese wooden horse carriage."*

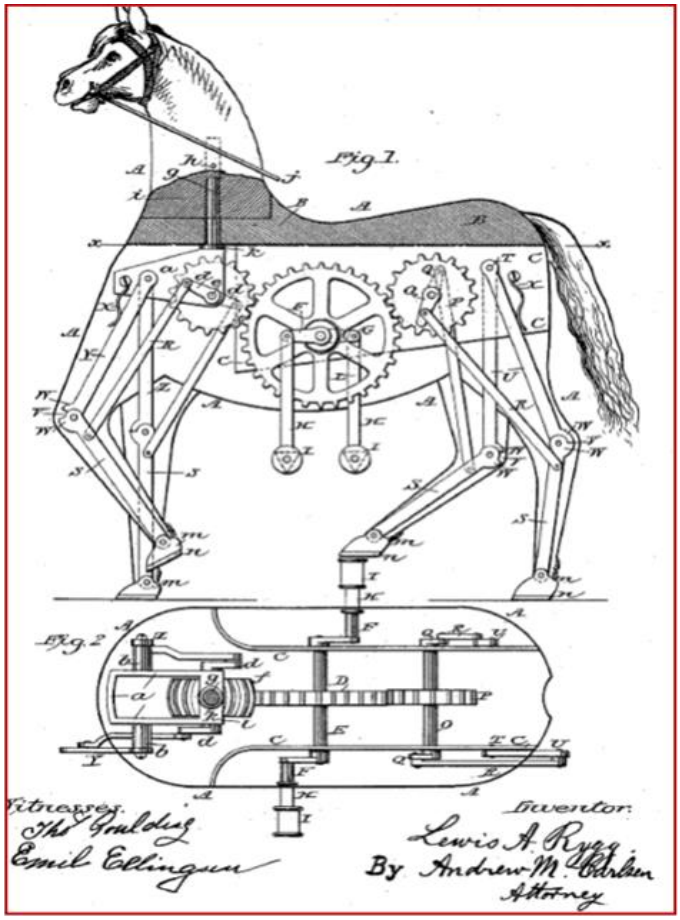
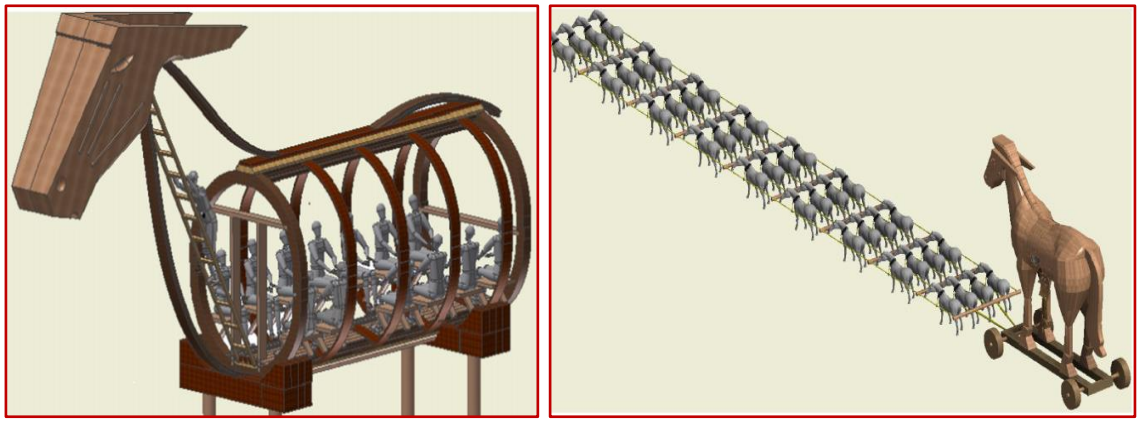



**Figure 2**. Invention of the mechanical horse of LA Rygg (American). U. S. Patent 491,927 (1893)

Figure 2 is the invention of mechanical horses by American scientists. In the belly of a machine horse is attached a transmission mechanism such as a belt, sprocket, or gear, ... The horse's body can be made of wood or other materials.

Figure 3 is the giant wooden horse product of Thomas G. Chondros et al. (2015). They recreated the wooden horse of Troy (based on the Greek mythological novel "The Trojan War"). In this horse's belly, there are many soldiers, there are stairs up and down like a large room. It took several dozen real horses to pull this fake horse into motion.

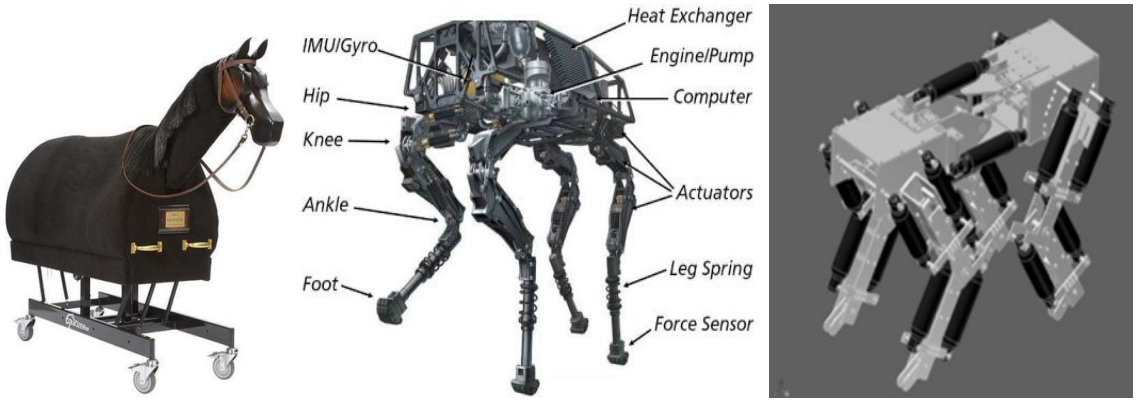


*a)* *b)*

**Figure 3.** Giant wooden horse

Figure 4a) is a mechanical horse for actors and athletes practicing riding and racing (Ivan Kulagin, 2020); Figure 4b) is a mechanical horse for people who practice nursing (Jack, 2022); Figure 4c) is a mechanical horse running on four wheels, used in filming (Katsuyoshi Tsujita et al., 2008); Figures 4d and e) is a 4-legged walking robot (Raibert et al., 2008).

*a)* *b)*




*c)* *d)* *e)*

**Figure 4.** Machine horses and 4-legged walking robots

Humans have always sought to create the most wonderful and useful mechanical horses to serve their lives. Depending on the perception, research ability, and usage of each person's mechanical horse, they have different ways of designing mechanical horses. All their products are interesting and deserve to be admired by posterity. Our group of authors also tried to design a mechanical horse after imagining the "wooden buffalo mechanical horse" in the work "Three Kingdoms". Our design is inherited but also different from the designs of previous researchers. Readers, please continue to read the following section to clearly see the advantages and disadvantages of our machine horse design.

## 2. Materials and research methods

### *2.1. Material*

In terms of design, the authors use Solidworks software to draw 3D shapes, calculate, simulate, and preview the results on the computer. In terms of manufacturing, the authors use steel to create the main bearing details of the machine horse. Some parts may use wood or plastic. Currently, we can use 3D printing to support the faster production of mechanical horses.

### *2.2. Research Methods*

*a) Speculating and analyzing the design of a mechanical horse*

According to *vol.* 102 of "Three Kingdoms", mechanical horses and wooden buffalo can go day and night, up and down the mountain. When they pulled out their tongues, they stood still, the soldiers could not move; when they attached their tongues, they ran like flying. We can speculate and analyze the magic of this type of wooden buffalo horse as follows:

*First,* Khong Minh is a talented man, so he can completely think of a type of horse that transports grain to replace soldiers. As for the level of perfection in the novel or not, it has not been proven. The war situation at that time was very short of means of transporting food, so the army leader was forced to think of mechanical horses and wooden buffaloes.

*Second,* qualitatively, in order for mechanical horses and wooden buffaloes to walk on their own without being pulled or pushed by humans, there must be a mechanical structure in the belly of those fake animals. However, around AD 230, mankind did not have a steam engine, an internal combustion engine, or an electric motor at all, so perhaps Khong Minh used a winding energy storage method. clock, that is, he put in the belly of the wooden animal a coil of steel springs (of course there was iron at that time). Soldiers just need to add a handwheel and turn it many times for that leaf spring to wind up (like winding a watch). The spring then slowly expands, converting the spring's elastic potential energy into kinetic energy. This kinetic energy is passed through other actuators and eventually to the four horse legs. That's how the horse can walk.

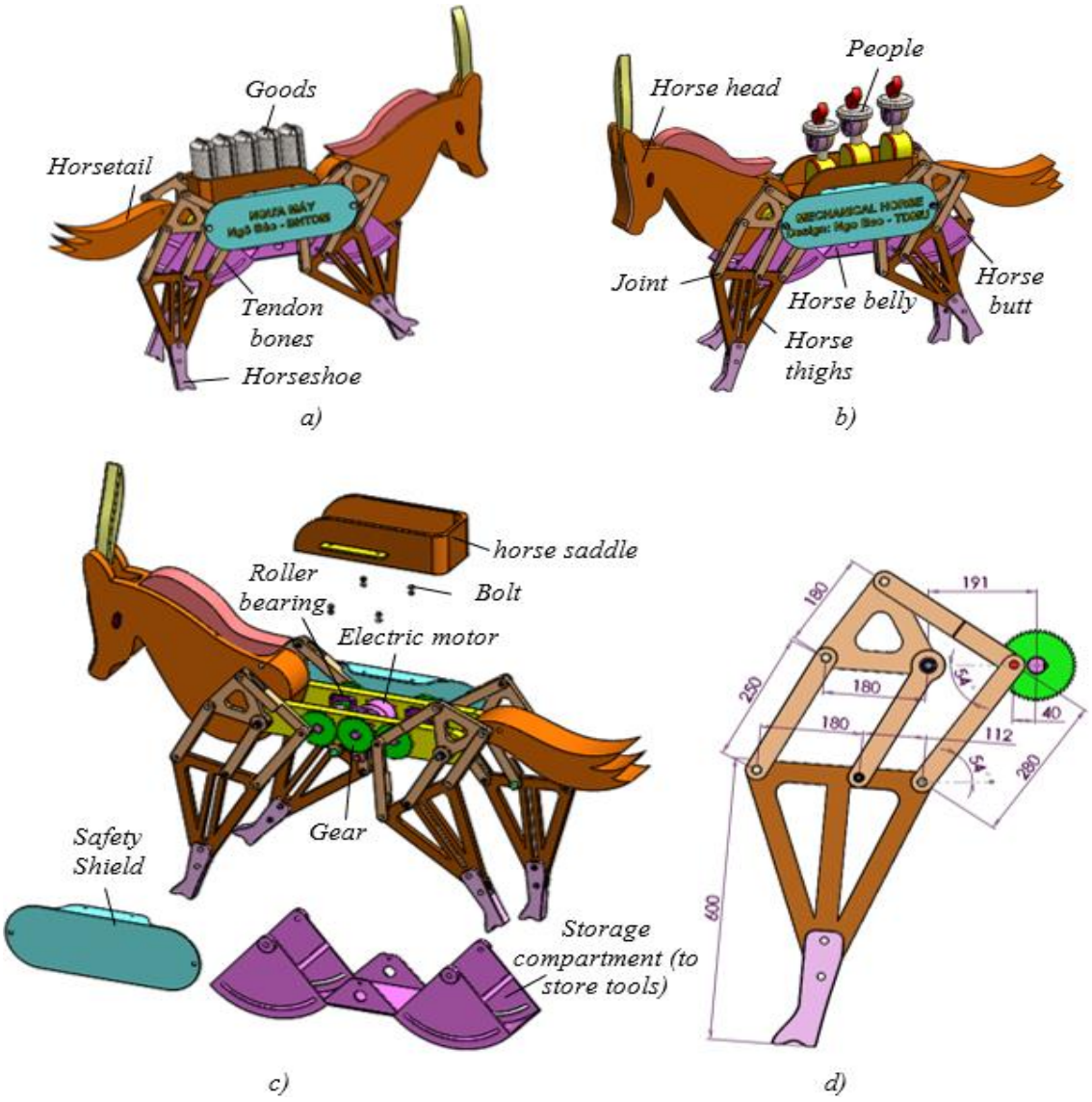
- *Third,* in quantitative terms, the energy source from the leaf springs slowly unfolding cannot be enough for the horse to carry the food all day and night. If considering the lowest level, the energy of 1 horse carrying two bags of rice with a total mass of 100kg, produced in 1 second is A1 = 750J, ie its power is P1 = 750W (1HP). So in 1 day and night, it must work as A = 750.24.60.60 = 64800000J. According to the law of conservation of energy, the leaf spring must store an amount of potential energy of at least Wt = 64800000J (ignoring all friction). This number of potential energy is too large, seemingly unimaginable for a leaf spring placed in the belly of a wooden buffalo horse. Indeed, in the way of modern automobile design, the elastic potential energy stored in the springs of a car is about Wt' = 1401016J on average. Comparing, we see Wt/Wt' = 64800000/1401016 = 46.25. That is the leaf spring in the horse's belly stores potential energy 46 times greater than the potential energy of the springs of the car's springs. This makes no sense!

*Fourth,* when attaching the tongue, the mechanical horses and wooden buffaloes can walk, but when pulling the tongue out, they are immobile. It is speculated that the tongue is like a key connecting the shaft with the rotating part of the machine. When there is no tongue, as well as no key, the machine parts slide over each other, unable to drive each other.

In short, Khong Minh's "wooden horse" is somewhat reasonable but also somewhat absurd. Perhaps author La Quan Trung exaggerates to make his work more interesting. It is reasonable that the “wooden buffalo machine” can completely walk or run; It also makes no sense in that the "wooden horse" can walk in the mountains day and night without providing energy.

In the next part, our team will show how to design a mechanical horse based on that rationality from Khong Minh's point of view. That is, we use a battery-powered motor (instead of a leaf spring) and gear transmissions (representing the drive mechanism described by Khong Minh) pre-installed in the belly of the mechanical horse. Of course, our battery-powered motor can't provide enough power for a horse to go all day, but it's only enough for a horse to run for a few hours.

*b) Sketch of the design of a mechanical horse*




*a) Cargo horse (view from the right); b) Human horse (pictured from the left)*
*c) Decompose a few parts to see the inner structure of the mechanical horse; d) Design a set of mechanical horse legs*

**Figure 5.** The 3D spatial perspective of the mechanical horse design

For ease of understanding, the author uses 3D images to illustrate the design and simulate the movement of a mechanical horse. This design is depicted in Figures 5, 6, and 7.

*Symmetry:* Horses are symmetrical, so just by looking at the details on one side, readers will understand the details on the other side.

*Power generator:* We can use a single-battery electric motor or battery just like in an electric bicycle. In case we need to use an AC motor, we use a single-phase power source like we usually use in the family. We can use a separate type of reducer or a type that is

attached to an electric motor. Here, the authors design an experimental horse, so it is possible to prioritize choosing an AC motor for convenient use of the power source, reducing the cost of charging. This electric motor is equivalent to a leaf spring that stores potential energy as analyzed by the authors above.

*Transmission mechanism:* Using a gear transmission combined with a rotary disc-connecting rod (transforming rotary motion into translational motion) and a 4-stitch hinge mechanism (transforming translational motion into rotational motion). The rods act as the skeleton of the horse that links the joint to create a parallel motion when the electric motor shaft starts to rotate. The way they work is shown in Figure 6.

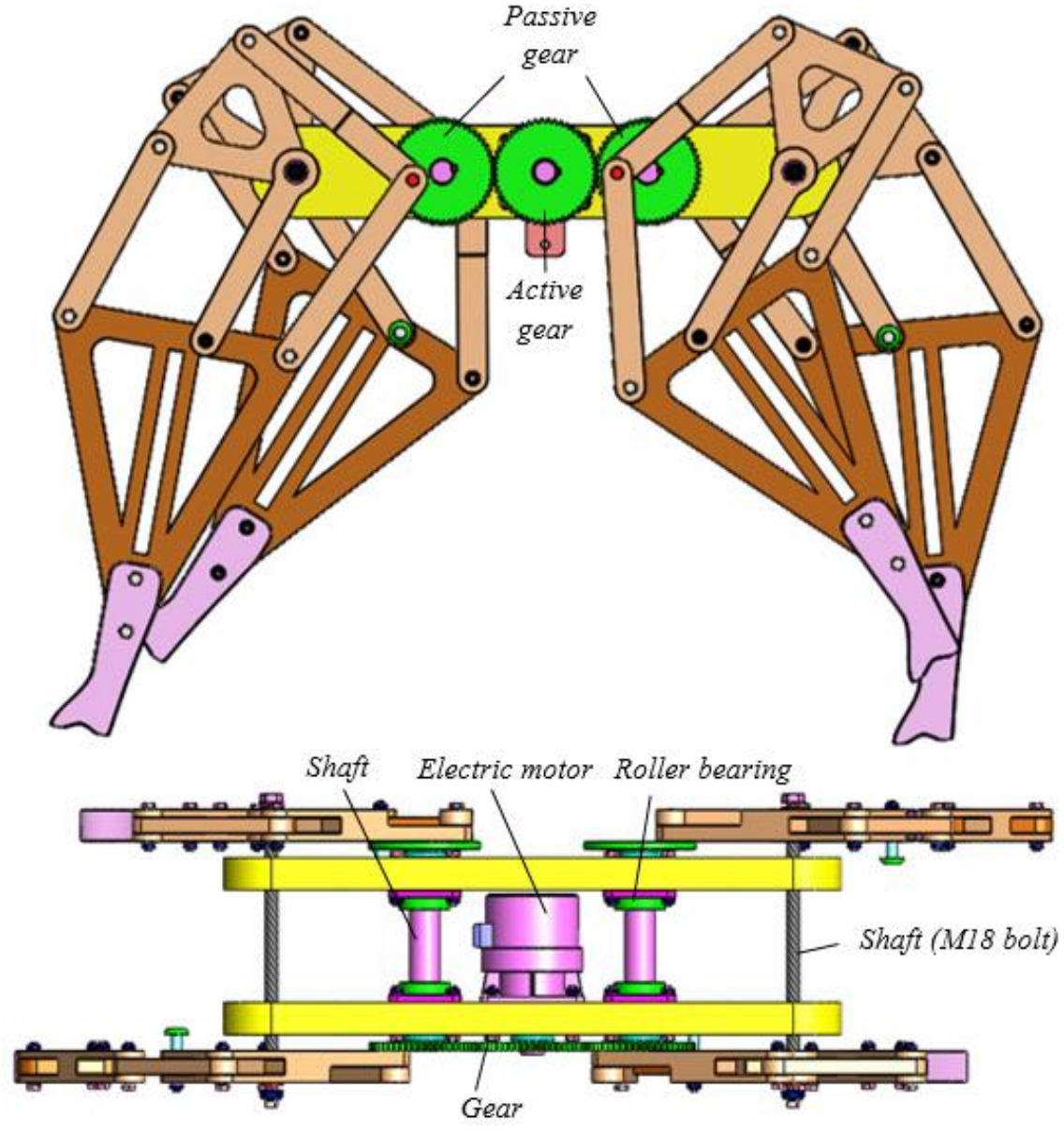



***Figure 6. Drive part of a mechanical horse***

*Description and analysis of the movement of the mechanisms (Figure 7):*

+ Drive gear (1) is installed by key on the output shaft of the reducer. When the output shaft of the reducer rotates with speed *n*, the drive gear (1) also rotates with speed *n*. From there, the motion was transferred to the passive gears and eventually made the four legs of the mechanical horse walk. Readers can watch the simulation video (following the YouTube link given at the end of this article) to clearly see the problem. Here, we can choose *n* in the range of 30 to 40 rpm, that is, we study a walking horse at a slow speed.

+ Rods (2), (8), (5), and frame (3) rotate around a fixed axis. We use special bolts at the joints. This type of bolt is designed to be in the bush, when tightening the nut, the nut is in contact with the bush, not touching the surface of the rotating parts.

+ Rods (4), (6), and (7) move parallel to the plane. We consider them to be in parallel motion because their motion is the union of rotation and translational motion.

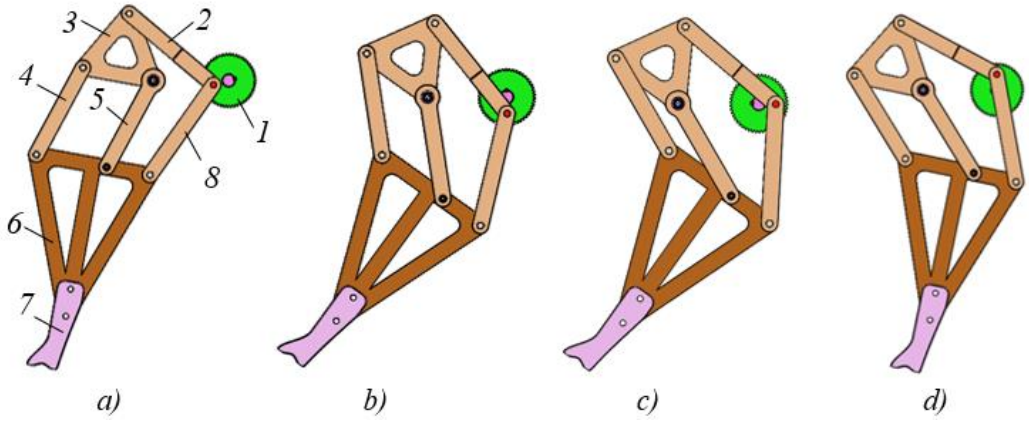



**Figure 7.** Horse foot states during one rotation of the electric motor shaft

***c) Calculation***

The purpose of the calculation is for us to choose the size, and weight of the wooden (or steel) bars and the power of the electric motor to match the load that the horse needs to transport.

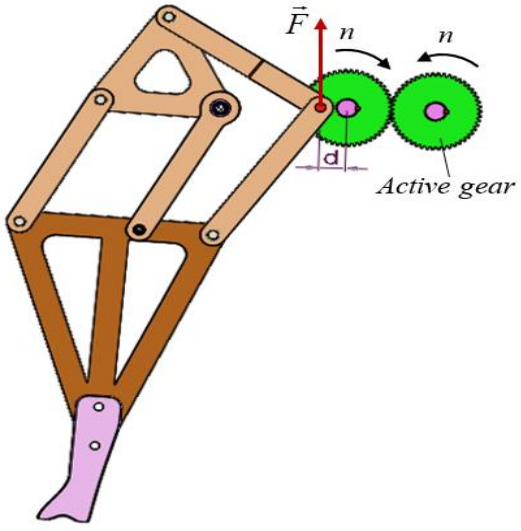



***Figure 8. Calculation of mechanical horses***

The mechanical horse is a truss structure with many stages and many joints, so the calculation process according to pure mechanics will be very complicated (see the calculation of the author FC Chen et al. (2012), in the article "On *the motion of a reconstructed ancient Chinese wooden horse carriage"*). That calculation method is so complicated that few people understand and apply it. Therefore, the authors of this article propose a simpler and easier-to-understand calculation as follows:

Suppose the electric motor power to be selected is P (in kW) and the number of revolutions of the output shaft of the reducer is n (in rpm). We have the formula for calculating the torque (Le Hoang Tuan et al., 1998) generated by the electric motor on the active gear (Figures 6 and 8):

$$M = \frac{9740.P}{n}$$

This torque is evenly divided to drive 4 horse legs; each horse foot has an active torque of

$$M_1 = \frac{M}{4} = \frac{9740.P}{4n} = \frac{2435.P}{n}$$

Then, the force to push/pull a moving horse's leg is: $F = \frac{M_1}{d} = \frac{2435.P}{d.n}$

If we include the friction force at the joints, bearings, etc. then we choose the friction force according to the normal mechanical system as $F_{ms} = 0.2F$. Then, we have the actual net force acting on a horse's leg:

$$F_{hl} = F + F_{ms} = \frac{2435.P}{d.n} + \frac{0,2.2435.P}{d.n} = \frac{2922.P}{d.n} \quad (1)$$

On the other hand, if we choose the weight of the whole machine horse and the goods (or people) that it needs to transport is m = 200kg. That is, each horse's leg bears the force:

$$F' = \frac{m.g}{4} = \frac{200.10}{4} = 500\ (N) \quad (2)$$

Identifying (1) and (2), we have: $\frac{2922.P}{d.n} = 500 \Leftrightarrow P = \frac{250.d.n}{1461}$ (3)

If we design the eccentricity d (see Figure 8) to be 0.04 meters, then in (3), we have:

$$P = \frac{250.0,04.n}{1461} = \frac{10.n}{1461} \quad (4)$$

*P* values according to several *n* values as follows:

| N. | Output speed n (rpm) | Electric motor power P (kW) |
|---|---|---|
| 1 | 30 | 0.21 |
| 2 | 40 | 0.27 |
| 3 | 50 | 0.34 |
| 4 | 60 | 0.41 |
| 5 | 70 | 0.48 |
| 6 | 80 | 0.55 |
| 7 | 90 | 0.62 |
| 8 | 100 | 0.68 |
| 9 | 110 | 0.75 |
| 10 | 120 | 0.82 |

From the table above, we can choose an electric motor (the type attached to the reducer) with a capacity of *P* and the number of revolutions of the output shaft *n* suitable for the design situation of the mechanical horse. For example, if we want to let the motor horse walk leisurely, choose an electric motor with a capacity of about 210W corresponding to the number of output shaft rotations of about 30rpm. If you want the horse to go faster, choose an electric motor with a larger capacity and number of output shaft revolutions. Normally, we should choose the power of the electric motor 2 to 3 times the calculated value for the safety of the horse and its long-term use.

When choosing the size, materials, etc. for the mechanical horse, we consider that the weight of the whole horse and the cargo it transports does not exceed 200kg. The body, head, and tail of the horse are made of plastic, wood, or box steel, designed according to Figures 4, 5, and 6. The foot of the horse is made of wood or steel to suit (can choose box steel 20 × 40mm, 1.2mm thick). We can choose the weight of a horse's leg so that it does not exceed 1/5 of the force it can withstand. That is, the weight of a horse's leg is not more than 500/4 = 125N, so the mass of a horse's leg is less than 12.5kg. Other details are selected in accordance with machine manufacturing rules.

## 3. Result

After calculating the force to choose an electric motor, considering the choice of material, type, etc., we can draw the details of the machine horse. From the detailed drawings, we have a drawing of a machine horse and convert it to a 3D perspective as shown in Figure 9. It is also easy to build a mechanical horse from there. Using only common materials available on the market today and a level 3/7 craftsman can make a complete mechanical horse.

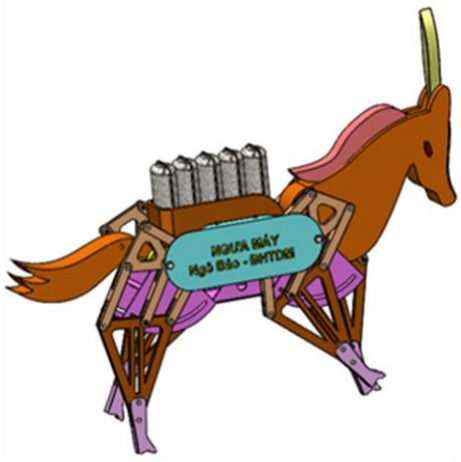


*Figure 9. Complete model of a mechanical horse*

## 4. Conclusions and recommendations

We have designed a model of a mechanical horse based on the point of view of Khong Minh in the novel "Three Kingdoms". However, we can only imagine and conjecture based on the brief description of Khong Minh. No one dared to claim that they made a mechanical horse exactly like Khong Minh's idea, but they speculated this way or that. Many documents claim that the food-carrying horse goes through the mountains and forests day and night as described by the lost Khong Minh or by La Quan Trung.

There have been many studies on mechanical horses to serve today's life. In the US, many people have patents on this topic. In China and Vietnam, people make wooden mechanical horses to make toys for children, supply to tourist areas, and serve entertainment.

Whether it's real or fictional, the image of the “Wooden buffalo mechanical horse” in the classic novel is still very attractive and raises questions for many readers. Our above article has partly solved that question for everyone. However, the more important thing that we want to mention in the above article is that the machine horse has many benefits and should be widely applied in today's life. Therefore, we have researched, designed, and edited a video simulating the operation of a mechanical horse, to help people better understand the magic of this 4-legged robot.

Our horse-making products can be applied to humans as recreational rides in tourist areas and as games for children. If possible, we will try to build a mechanical horse. From there, develop more strengths and correct its limitations.

We believe that, nowadays, when electric vehicles are used more and more, electric-powered horses should also be built more to serve people's entertainment.

*Link to watch simulation video:* https://youtu.be/t50B6FUHpqA

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