A SYSTEMATIC APPROACH FOR THE RESTORATION OF LU-BAN'S WOODEN HORSE CARRIAGE OF ANCIENT CHINA

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ABSTRACT - A legendary walking machine "Wooden Horse Carriage" was invented by Lu Ban (~ 507-444 BC) during the period of China's Era of Spring and Autumn. This work introduces historical literature and presents an approach for the systematic restorations of this lost invention. A design, consisting of a walking horse with four identical leg mechanisms of 8-bar type and a carriage, is synthesized and build. When left on a slope, the device moves down without human intervention. This proves that such an invention may be feasible.

KEYWORDS: Walking machine, history of Chinese machinery, Wooden Horse Carriage

INTRODUCTION

Ancient China was outstanding in mechanical technology before the 15th century. Many ingenious devices were invented. However, it was unfortunate that they were unable to keep complete documentation and the finished objects, thus preventing many of the inventions to be passed down to latter generations. The latter generation could only regard their inventions as novelties, and some even questioned these inventions as being preposterous.

Studies and publications regarding walking machines appeared only in the last hundred years. However, according to ancient Chinese records, a walking machine namely "Wooden Horse Carriage" (a device that mimics the horse using mechanical legs) by Lu Ban might be created before the time of Christ. This design was treated as a novelty and quickly disappeared.

Very little literature regarding such an invention was recorded. This work will not deal with the credibility of historical literary works. It supposes that Lu Ban's wooden horse carriage existed, and tries to present the feasibility of its operation using a systematic approach to synthesize the leg mechanism.

Historical background and records regarding Lu Ban's wooden horse carriage are introduced and discussed first. Works involved in restoration in the past years are presented. A possible design is synthesized. And, finally a reproduction of this invention is presented.

HISTORICAL BACKGROUND AND RECORDS

Lu Ban (••) (~ 507-444 BC) with Gongshu (••) as his original family name, believed to be a native of Dun Huang (••) in ancient China, was a master carpenter and inventor in the Kingdom of Lu (••) during the Era of Spring and Autumn (••••). What fascinated people most were his design of the wooden kite and the wooden horse carriage. According to legend, Lu Ban was a filial son. He built a wooden horse carriage for his aged mother so that she would not tire herself when she went out.

There were many records describing his wooden bird, but only a few about the wooden horse carriage. It first appeared in Chapter Ru Zang of Lun Heng (•••••) written by Wang Chong (••) (~ 27-97 AD) in East Hang Dynasty (••). It states: "It is said that Lu Ban was mourning of the loss of his mother. He built a wooden horse carriage that was well equipped and needed

no manual intervention. When his mother rode on, it sped away never to return. ”(• •)

Fig. 1 Lu Ban (• •) (~ 507-444 BC)

Wang Chong’s work was primarily a response to book Ru Shu (• •). There was a part in it that questioned the credibility of Lu Ban’s flying contraption that could stay in the sky for three days. Wang Chong believed, however, that if Lu Ban’s carriage could move automatically without stopping, then his kite could also fly for three days without falling. If the wooden carriage could not move on its own, then when Lu Ban’s mother was riding in the carriage, the carriage should have stopped moving somewhere, enabling Lu Ban to find his mother along the three-day carriage route. According to historical records, however, Lu Ban’s mother was never found.

Lu Ban lived in Dun Huang, a place full of mountainous slopes. This might also point out that his carriage could move in the rugged terrain possible based on inertia and the conservation of energy.

The wooden horse carriage of Lu Ban was invented under such condition; but the invention was treated as a novelty and quickly disappeared. All the relevant information about his invention was not recorded because the scholars during the time were ignorant of scientific knowledge. Nevertheless, it is the earliest story of ancient Chinese walking machine.

Based on Wang Chong’s Lun Heng, we could prove the existence of Lu Ban’s wooden horse carriage indirectly. If the wooden kite existed, then the carriage must have existed also because the design of the flying device should be more difficult than the ground carriage. In addition, if the carriage were operated by linkage mechanisms, it would not be a problem for a carpenter like Lu Ban. The most critical issues should be the correct dimensions and assembly of the parts. To somebody who had no modern technological background like Lu Ban, the structure of the device would be based on experiments done with rich engineering experiences. Therefore, the creation of the wooden horse carriage should be possible.

RESTORATION STUDY

In the past long history, very few scholars studied the lost ancient Chinese machinery, those with some literary records but without surviving hardware. In recent years, the scholars who believe that Lu Ban’s wooden horse carriage was an enigmatic ancient invention have been reproducing the device.

Around 1986, Wang Chien (• •) of Urumqi in Xin Jiang, built a wooden horse carriage based on his ingenious experience and sense of practicality, Figure 2. This design is composed of a

walking mechanism with leg function and a trailer with balance function. The walking mechanism has four sets of 8-bar linkage with the same configurations.

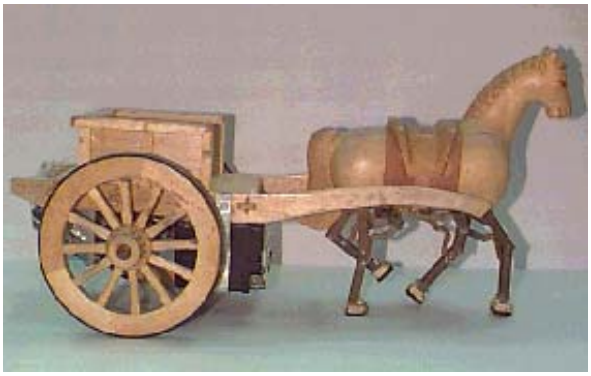

Fig. 2 Wang Chien's wooden horse carriage

NCKU'S APPROACH

In 1994 the author at National Cheng Kung University (NCKU) (Tainan, TAIWAN) started a systematic research efforts on the lost Wooden Horse Carriage [1-5]. Subject to limited historical records and technological constraints in ancient era, all possible design concepts of 4-leg walking machines with linkage configurations are synthesized and built, based on the Creative Mechanism Design Methodology developed by the author [6-8]. The approach includes the following steps (Figure 3):

Step 1. Ancient Machinery

The reconstruction of ancient machinery requires exhausted literature study to define the problem and come up with design specifications. It is also important to be familiar with the available science theories and technologies of the subject time period.

Step 2. Original Design

The second step is to conclude basic topology characteristics as well as design requirements and constraints from existing designs based on literature study. Any existing design can be selected as the original design. If no original designs are available, go to Step 4 subject to the design specifications.

Step 3. Generalized Chain

The third step is to transform the original design into the corresponding generalized chain according to the principles and rules of generalization.

Step 4. Atlas of Generalized Chains

The fourth step is obtaining the atlas of generalized chains that have the same numbers of links and joints as the generalized chain obtained in Step 3 by applying the technique of number synthesis.

Step 5. Atlas of Feasible Specialized Chains

The fifth step is to have the atlas of feasible specialized chains with assigned types of links and joints subject to the concluded design requirements and constraints for every generalized chain obtained in Step 4.

Step 6 Atlas of Designs

The sixth step is to particularize each schematic format from the atlas of feasible specialized chains, according to the motion and function requirements of the ancient machinery, to establish the atlas of all possible designs.

Step 7. Atlas of Reconstruction Designs

The last step is to obtain the atlas of reconstruction designs from the atlas of designs by utilizing the mechanical evolution and variation theory to perform a mechanism equivalent transform. Ancient science theories and technologies of the subject time period are applied to find out appropriate and feasible mechanisms that can be considered as the reconstruction designs.

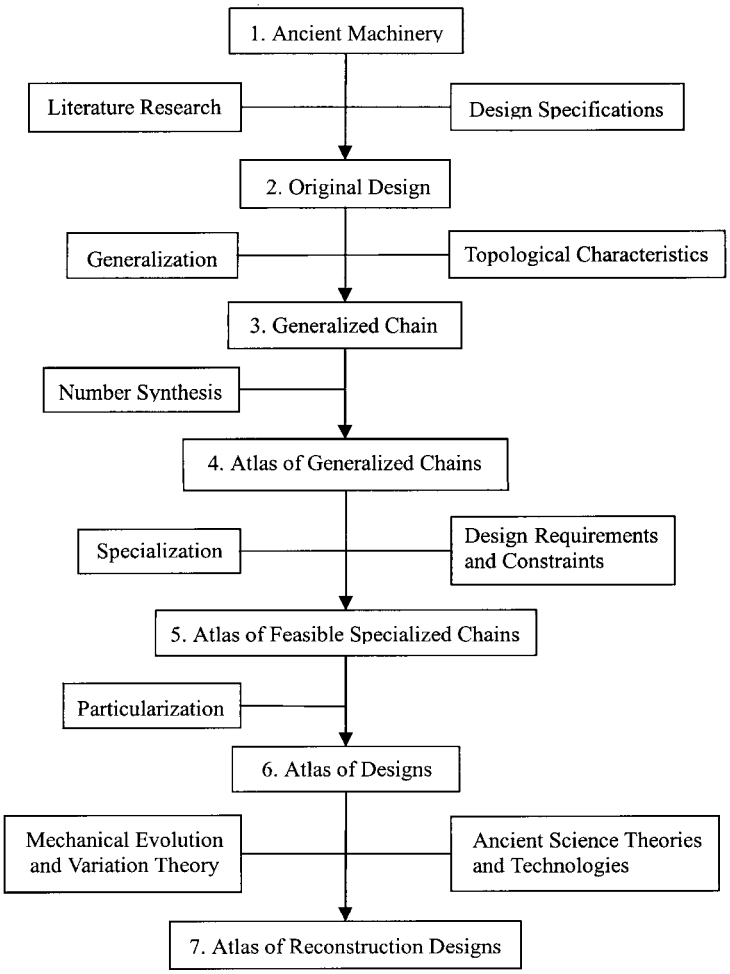

Fig. 3 Reconstruction design procedure [8]

All feasible designs for the leg mechanisms with one degree of freedom and up to eight-bar are synthesized. Figure 4 shows some designs of six-bar linkages, and Figure 5 shows some design of eight-bar linkages.

One solution from Figure 5 is selected as the leg mechanism for detail kinematic design and force analysis, Figure 6. And, its physical model is built, Figure 7. This design requires only a small force to push or pull to walk up a reasonable slop. And when left on a slope, it can move down without human intervention due to the gravity. This could provide a possible evidence that the legendary wooden horse carriage in ancient China may be feasible.

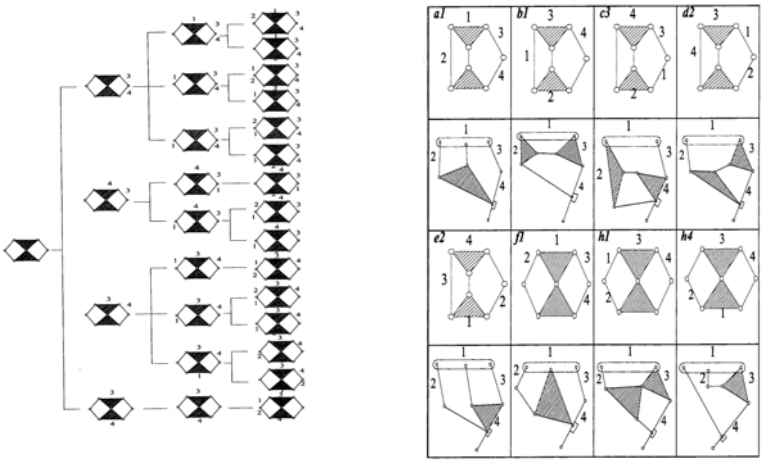

Fig. 4 Some specialized chains for leg mechanisms of 6-bar type [3]

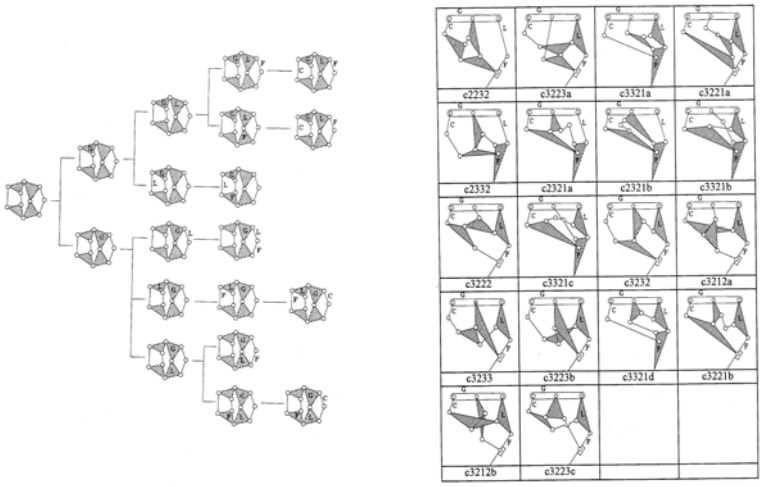

Fig. 5 Some specialized chains for leg mechanisms of 8-bar type [4]

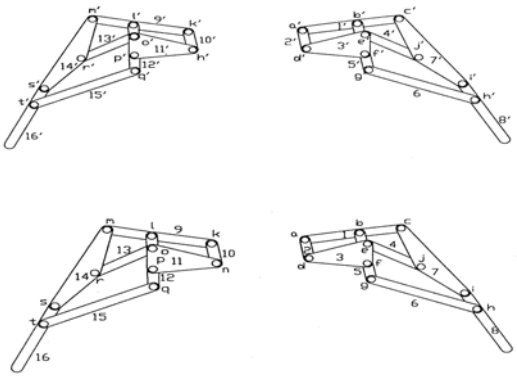

Fig. 6 Leg mechanisms of 8-bar type [4]

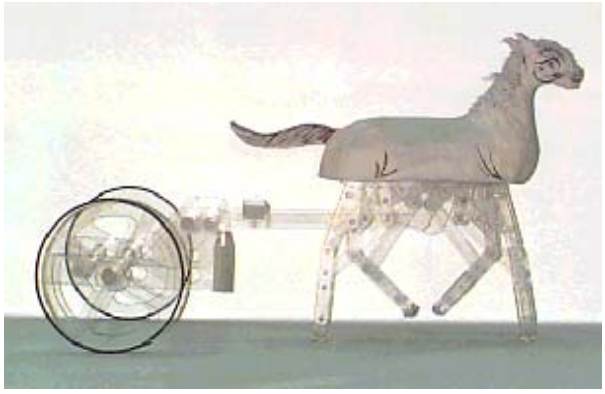

Fig. 7 An NCKU's wooden horse carriage

CONCLUSIONS

This work introduces historical literature and presents restoration works regarding the earliest ancient Chinese walking machines, the Wooden Horse Carriage of Lu Ban around twenty-five hundred years ago.

Due to incomplete documentation and the lost of finish objects, the original structure of Lu Ban's wooden horse carriage has become a mystery in the long past years. A systematic approach, based on the creative mechanism design methodology developed by the author [6-8], is applied to generate all possible designs subject to ancient science theories and technologies. A design of the wooden horse carriage consists of a four-legged walking machine with identical leg mechanisms of eight-bar type and a trailer is synthesized, and a physical model built. This carriage is pushed to move forward and pulled to move backward. When left on a slope, this design moves down without human intervention. This proves that such an invention may be feasible as indicated in Lun Heng written by Wang Chong (~ 27-97 AD) in East Hang Dynasty, the earliest historical record of this legendary design.

The result of this work provides some trace for the historical development of ancient Chinese walking machines.

ACKNOWLEDGEMENTS

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