History of Mechanical Technology and Mechanical Design 2012

Edited by
Hong-Sen Yan, Jianbin Zhang,
Guanglin Wang, Kuei-Yuan Chan,
Yidu Zhang, Chunjie Wang and Hai Zhang

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History of Mechanical Technology and Mechanical Design
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March 23-25, 2012, Taiwan

Edited by

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Preface

The present volume contains selected papers from the proceeding of International Conference on History of Mechanical Technology and Mechanical Design -2012(ICHMTMD2012). The conference is developed from China-Japan International Conference on History of Mechanical Technology (CJICHMT). The 1st CJICHMT was held in Beihang University on Oct. 12-14, 1998, sponsored by Beihang University, and the Co-sponsors include Chinese history of machinery Society, Japan Society of Education for History of Technology and Chiba Institute of Technology etc.. CJICHMT is initiated by Prof. Guo Keqian (professor of Beihang University), Prof. Edoh Gendai (Chiba Institute of Technology) and Prof. Shimotsuma Yorikazu (Kansai University). The purpose is to build a platform of academic, cultural and information exchange for researchers of China and Japan, so as to promote the development of study of history of mechanical technology. The conference holds once every two years. In the 4th conference of 2004, for expanding the fields of exchange, the organizing committee decided to rename the conference to China-Japan International Conference on History of Mechanical Technology and Mechanical Design (CJICHMTMD). And in the next year (2005), as a special case, the 5th CJICHMTMD was held in Chiba, Japan. The latest conference, namely, 8th CJICHMTMD was held from Oct.31 to Nov.1, 2010 in Jiaozuo, Henan Province, sponsored by Beihang University, and undertaken by Henan Polytechnic University (HPU). The major topics of the 8th CJICHMTMD cover History of Mechanical Technology, Mechanical Design and Mechanical Manufacture. Now, CJICHMTMD is attracting more and more attentions come from China and Japan. CJICHMTMD has been sponsored by National Natural Science Foundation of China in the former times.

For expanding the influence of the conference on history of mechanical technology and mechanical design, the organizing committee of 8th CJICHMTMD decided to rename this conference the International Conference on History of Mechanical Technology and Mechanical Design and that the next conference on History of Mechanical Technology and Mechanical Design will be held in Taiwan during March 23-25, 2012 and undertaken by National Cheng Kung University.

There are more than 100 papers submitted to International Conference on History of Mechanical Technology and Mechanical Design-2012 from Mainland China, Taiwan and Janpan. All of the papers were subjected to peer review by at least two expert referees, and some excellent papers were selected to publish in this volume.

International Conference on History of Mechanical Technology and Mechanical Design 2012 will be held with the great effort of many people. As the organizers of the conference, we would like to take this opportunity to express our appreciation for the kind support and high quality contributions from all the contributors and delegates. And we wish to express our thanks to the Honorary Chairmen of Conference Edoh Gendai (Japan) and Guo Keqian (China). Thanks should also be given to the staff of the this conference who paid a lot of hard work in call for paper, paper edition, conference arrangement, and so on. We especially should give the thanks to Prof. Hong-Sen Yan and Associate Prof. Kuei-Yuan Chan of National Cheng Kung University, Prof. Zhang Yidu, Prof. Zhang Jianbin and Prof. Wang Chunjie of Beihang University, Prof. Zhang Hai of Henan Polytechnic University and Prof. Wang Guanglin of Harbin Institute of Technology for their fruitful efforts during the paper organization of the conference. Finally, we wish to express our thanks to Trans Tech Publications for publishing the volume.

Conference Organizers

Beihang University

National Cheng Kung University

Japan Society of Education for History of Technology

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Historical Development of Reconstruction Designs of Antikythera Mechanism

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Key Words: Antikythera mechanism, Greece machine, Reconstruction design

Abstract. Antikythera mechanism is an ancient Greece machine excavated in 1900. The damaged remains and ingenious mechanical structure resulted in man's thirst to decode this mechanism. This paper reviews the historical development regarding reconstruction designs of Antikythera mechanism. The origin, the recovering process and the related historical records are introduced first. Available reconstruction designs, which are classified into the orientation of mechanism, the decoding of modern technology including the appearance, the functions of the exterior dials and the interior structure, other research and the authors' work are presented. Then, based on the viewpoint of mechanisms, the mechanism analysis of one feasible reconstruction design with the complete interior structure, by the authors, is presented. This new design to generate all known output functions also provides a possible embryo of Antikythera mechanism.

Introduction

In 1900-1901, a party of Greek sponge-divers was driven off course by gales and discovered unexpectedly an antique shipwreck, containing a great quantity of treasuries and an unnoticed wooden box, off the island of Antikythera. In 1902, it was found that an amazing arrangement of bronzed gears, triangles had been cut out of the middle of the wheel, was hided under the wooden box. The unknown excavation with complex structure was suggested as a mechanical device for making accurate measurements or calculation. As far as all known precious artifacts were considered, there was not anything like this device. Therefore, this strange device was just named "Antikythera mechanism" in accordance with the excavated position.

This staggering finding is the beginning of story. It resulted that several scholars were much eager to understand what Antikythera mechanism is. Through numerous efforts during the past 110 years, it is confirmed that Antikythera mechanism was a mechanical calculator with the dials on front and back plates, as shown in Fig. 1. For the front dial, it can display the cyclic motions of heavenly bodies on the fixed inner annulus that is divided into twelve divisions for Zodiac. And it also can demonstrate the Egyptian calendar on the rotatable outer annulus that is divided into twelve 30-day months and 5 extra days. For the back, the upper had one spiral dials with five turns and two subsidiary dials with quartered circles. It can calculate the cyclic records of both astronomical phenomena and festivities, including the Metonic, Olympiad and Callippic cycles respectively. And, the lower had one 4-turn spiral dials and one subsidiary dial with three divisions. It can predict the time of eclipses, Saros cycle and Exeligmos cycle, respectively [2-21]. However, due to the lost and damage of excavated mechanism, the known reconstruction designs are still incomplete. The process of reconstruction design was endless until now.

This paper introduces historical development of the reconstruction designs of Antikythera mechanism in the past years. Then, the interior structures of one new reconstruction design with the complete interior structure by the authors are analyzed.

Historical Background

Antikythera mechanism, the great artifact datable between 150 BC and 100 BC, is confirmed as the oldest geared instruments. All understandings were derived from the decoding of surviving evidence, including the inscriptions, the structure and the material. For the viewpoint of manufacturing technique, until the appearance of the first astronomical clock in the 14th century, there was not a mechanical device comparable to this great mechanism.

(a) Front (b) Back

Fig.1 A reconstruction model by Yan and Lin [1]

Indeed, in the historical records, the only related description appears in Cicero's writings, which describe the astronomical apparatuses used by the Greek astronomer Posidonius, in Rohdes. Among which, similarities can be found between one device and Antikythera mechanism. However, it was merely the evidence that such technology could be arrived in this period, not the evidence for the existence of Antikythera mechanism in the period.

Through decoding the month names of calendar in the mechanism, Freeth et al. confirmed strongly that the mechanism's calendar is identical to the Corinthian calendar coming from the calendar of Tauromenion in Sicily. It also explained that the Antikythera mechanism should be from Corinthian colonies, and a certain workshop adopted from Archimedes seemed to be likely the origin [19].

Historical Reconstruction Designs

The contemporary newspapers published frequently reports about the treasure of Antikythera shipwreck and the procedures of the salvage in 1900-01. The appearance of complicated structure of Antikythera mechanism in 1902 ignited people's interests quickly, and then its study results in an academic and archaeological trend more than 110 years. In what follows, historical development of the reconstruction work of Antikythera mechanism is introduced.

Early Mentions (1902 - 1920). Not only Greek but also the researchers around the world have successively studied this mechanism since Stais's finding. Around 1905, A. Rehm was the first man to define that Antikythera mechanism was an astronomical calculator. He believed that this mechanism should be a planetarium resembling the sphere of Archimedes or Posidonius that Cicero described in 100 BC. However, against the concept for a spherical planetarium in 1910, P. Rediadis claimed that the mechanism was a kind of astrolabe in ancient Greece and was used to measure the altitude of the stars in the heaven adjusted to the season.

By any means, due to the limitation of technology at that time, the coherent explanations for Antikythera mechanism, either the exterior appearance or the interior structure, were not presented.

Price's Reconstruction Design (1950s - 1970s). The first reconstruction design with the systematic concept, shown in Fig.2, was delivered by Derek J. de Solla Price [2-4]. He cooperated with G. Stamiris and C. Karakalos to take a thorough study with the application of the image technology to detect the fragments. Since then, the reconstruction design by Price, although not complete, was accepted extensively. In 2000, M. Edmunds and P. Morgan presented a reconstruction concept, a planetary gear train with a pin-in-slot joint, to demonstrate the motions of Venus and Mars on the basis of Price's reconstruction [5].

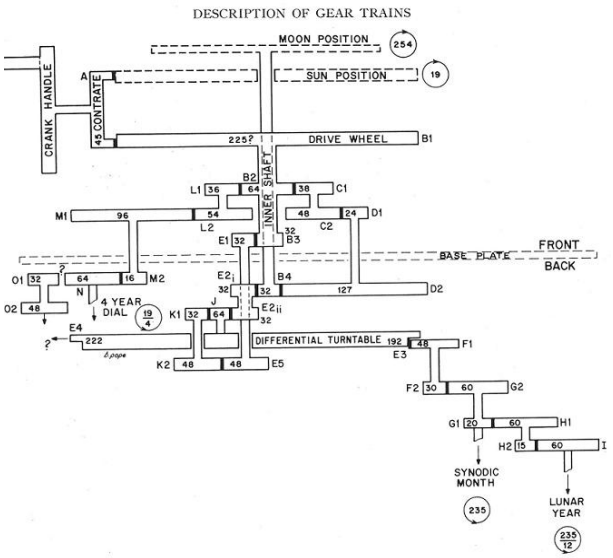

Fig. 2 Reconstruction design by Price [2-4]

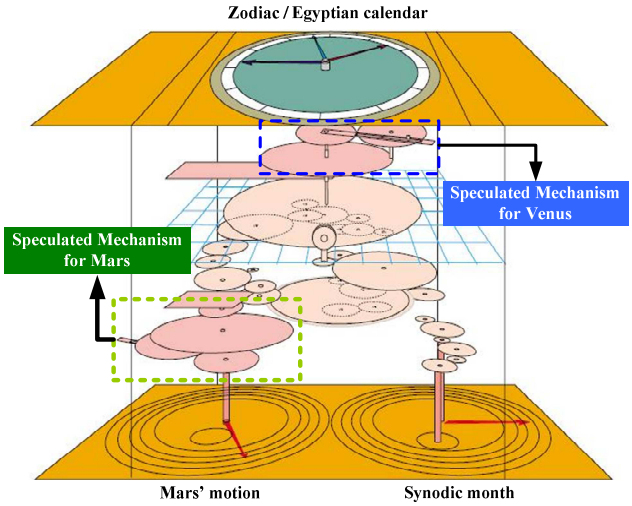

Fig. 3 Reconstruction design by Edmund and Morgan [5]

Wright's Reconstruction Design (2002 - 2007). The second reconstruction design, as shown in Fig.4, was delivered by M. T. Wright [6-16]. This series of studies shows a new decipherment that is different to Price's one. Based on the detection records obtained from the cooperation with A. Bromley, Wright modified some parts of Price's design. The partial mechanisms for back upper dials were identified. Most important of all, the discovery of a pin-in-slot joint verified the feasibilities of design concepts by M. Edmunds and P. Morgan, and himself respectively. It resulted that the rotational motion with the periodically variable speed led into the concept of the reconstruction design gradually.

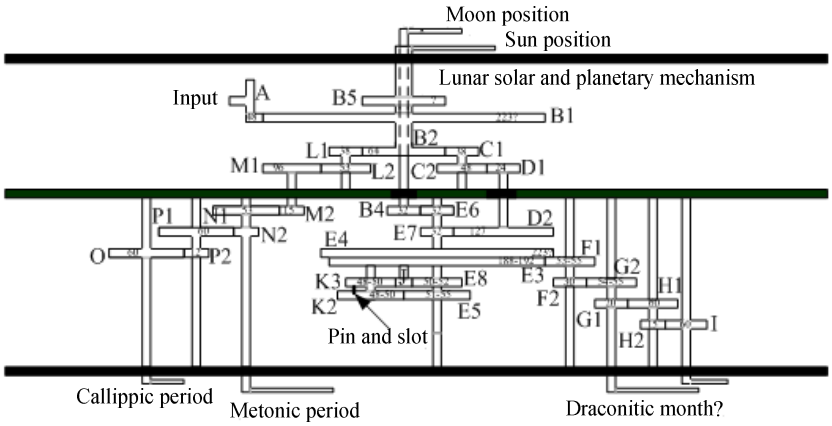

Fig. 4 Reconstruction design by Wright [6-16]

Reconstruction Design by Freeth et al. (2005 - date). The third reconstruction design, as shown in Fig. 5, was delivered by Freeth et al. through the project of The Antikythera Mechanism Research Project [17-21]. In 2006 and 2008, they presented new reconstruction designs, based on the decoding of the inscriptions and glyphs and the identification of the interior structure. The reasonable designs can demonstrate not only the ancient astronomy but historical cultural records. Furthermore, their great achievement also consisted of the decoding of numerous glyphs and inscriptions. Indeed, the design by Freeth et al. provided the most complete information about Antikythera mechanism.

Other Research and Designs. Due to the efforts of previous studies, reconstruction designs of Antikythera mechanism attracted more attentions. In 2008, T. Koetsier presented the historical development of reconstructing the Antikythera mechanism through a thorough analysis of each

previous design and Greek astronomy [22]. In 2008, J. Marchant introduced the full story of the quest for Antikythera mechanism through interviews with those who studied or investigated this device before [23]. Rossi, in 2009, presented the study of the components of alloy of gears and the shape of teeth and confirmed that such manufacture technique of the sophisticated gear was developed highly before Antikythera mechanism by the finding of a gear dated to the third century BC [24]. In 2010, Evans et al. presented their fresh design, i.e., the non-uniform Zodiac divisions on the front dials, to demonstrate the solar and the planetary motions [25].

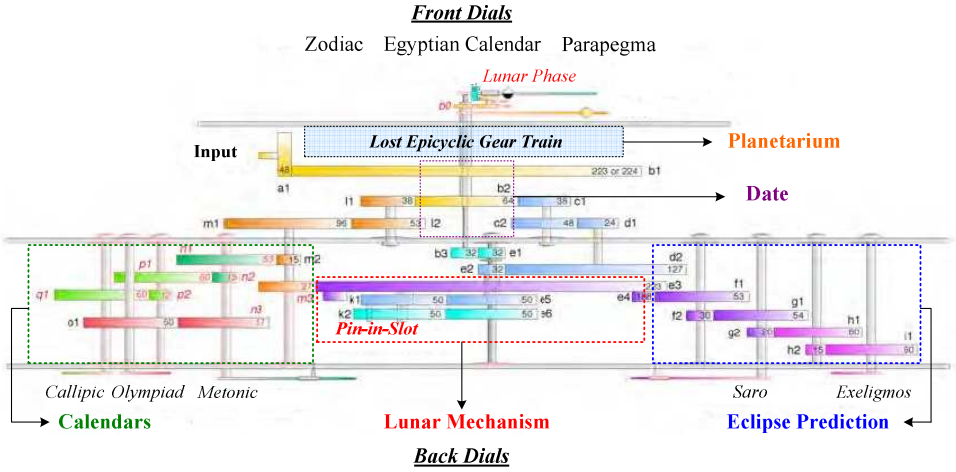

Fig.5 Reconstruction design by Freeth et al [17-21]

Authors' research. In 2011, Yan and Lin presented a design approach to reconstruct the unclear and lost interior structures of the existing designs systematically [1, 26]. Based on the study of historical literatures and astronomy, the design specifications and constraints are concluded through the detected evidence, the decoded information, ancient astronomy, ancient astronomical instruments, and mechanism analysis. Then, in accordance with the concepts of generalization and specialization, all feasible design concepts subject to the design constraints, for the unclear and lost mechanisms, are synthesized. Certainly, new reconstruction designs with complete interior structure are generated by combining the feasible design concepts of the unclear and lost mechanisms and the existing mechanisms.

Fig.6 is one of the possible reconstruction designs synthesized through the proposed design approach. This design satisfies the surviving evidence known at present and the technology and science of the subject's time period.

Mechanism Analysis

By Fig. 6(a), it is understood that the interior structure of Antikythera mechanism consisting of five subsystems: date subsystem, lunar subsystem, eclipse predict subsystem, calendrical subsystem and lost subsystem. In what follows, the mechanism of each subsystem is concluded.

Date Subsystem. The date subsystem serves to display daily motion on the outer annulus of front dial for the Egyptian calendar to indicate the date. Its structure is detected from the excavation and confirmed as a three-bar mechanism with three joints and one degree of freedom [2-21]. The contrate gear is connected to the input crank driven by hands.

Eclipse Prediction Subsystem. The eclipse predict subsystem serves to display the Saros and the Exeligmos cycles on the back lower dials. The corresponding structure is discovered from the excavation definitely. It is confirmed as an external gear train with six members, nine joints and one degree of freedom [6-21].

Lunar Subsystem. The lunar subsystem serves to display the lunar anomaly on the inner Zodiac annulus of front dial. It is confirms as a seven-bar mechanism with ten joints (including six revolute joints, three gear joints and one pin-in-slot joint) and two degrees of freedom. And this planetary

gear train with a pin-in-slot joint can demonstrate Hipparchus' first lunar theory of which the existence time is consistent with Antikythera mechanism [17-21]. Furthermore, the design with coaxial input link and output link is applied in this subsystem. A detected feature with a visible regular pentagon is regarded as the representation of this coaxial design. No matter what arrangement of axes, the design would relate to the manufacturing possibility in ancient time.

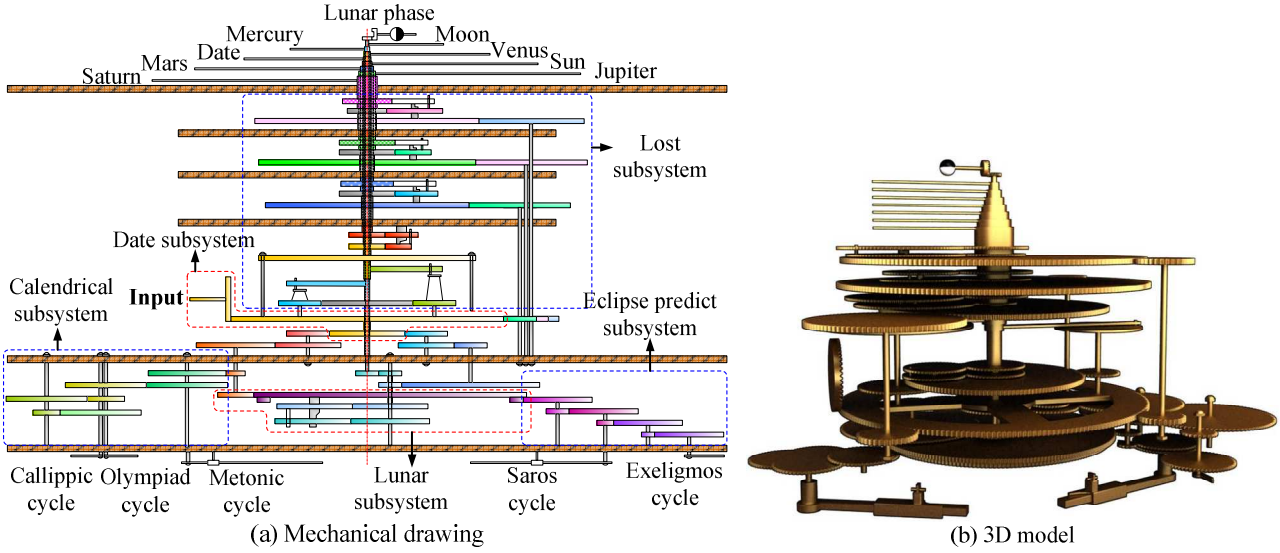

Fig. 6 One reconstruction design by Yan and Lin [1]

Calendrical Subsystem. The calendrical subsystem serves to display the Metonic cycle, the Olympiad cycle and the Callippic cycle on the back upper dials. The directions of the outputs for the Metonic cycle and the Olympiad cycle are clockwise and counterclockwise, respectively. The one for the Callippic cycle is still uncertain. Only two gears respectively with 15 and 60 teeth are identified. Therefore, based on the known evidence, the decoded functions and the concept of simpler design, this unclear calendrical subsystem is reconstructed as an external gear train with six members, nine joints and one degree of freedom [1, 26].

Lost Subsystem. The lost subsystem is suggested to generate the solar and planetary motions; however, the mechanisms corresponding to these functions are lost completely. Based on ancient astronomical theories of the subject's time period, feasible designs of the lost subsystem are reconstructed to demonstrate the solar anomaly and the retrograde motions of planets. For the superior planetary motions, including Mars, Jupiter and Saturn, the corresponding mechanisms are planetary gear trains with five members, seven joints and one degree of freedom. For the inferior planetary motions, including Mercury and Venus, the corresponding mechanisms are planetary gear trains with four members, five joints and one degree of freedom. For the solar motion, the corresponding mechanism is simple gear train with five members, seven joints and one degree of freedom.

This introduction provides an overall reorganization of Antikythera mechanism. Especially for the unclear calendrical subsystem and the lost subsystem, all feasible reconstruction designs are synthesized by considering the design principle of the simpler structure. However, due to the lack of surviving evidence, other possible conditions can be discussed further, the lost subsystem with two degrees of freedom for example.

Conclusions

The study of Antikythera mechanism is an interesting task in the reconstruction of ancient machines. Even if the surviving fragments of Antikythera mechanism are damaged, many scholars sought to find out the appropriate solutions. By reviewing historical development of the construction designs of Antikythera mechanism, the information, including the exterior appearance, the output functions

and the surviving interior structures of mechanism, are understood. In accordance with each known output requirements, the interior structure of existing designs is divided into five subsystems. In addition, the mechanism analysis of complete interior structure reconstructed by the authors is presented. This new design to generate all known output functions can provide a possible embryo of Antikythera mechanism for readers.

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Reconstruction Study on the Bellow of Blast Furnace in Liao Dynasty—A Case of the Iron Smelting Site at ShuiquanGou, Yanqing in Beijing

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Abstract. Based on historical documents and field survey, the wood bellow of No.3 iron smelting furnace in Liao Dynasty was reconstructed at Shuiquangou, Yanqing in Beijing. Its ultimate wind pressure and the speed were estimated. The ventilate ability for its portion was calculated respectively. Furthermore, the flow field in the furnace blasted with the wood bellow was simulated with software FLUENT. The effect on the iron smelting techniques for single-tuyere blast furnace with this blast ability of the bellow was discussed.

Introduction

Iron smelting technology was well developed in ancient China. From about 600BC, Chinese began to produce cast iron by using blast furnace, which made Chinese economic and society keeping ahead the world in the Middle Age. As the economics was so prosperity in Song and Liao Dynasty (AD 916--AD1165), much ironware is needed, the better smelting technology, blast capability and smelting efficiency was seriously required. It's very important to study the history of metallurgy and mechanics in those times. It is also necessary to investigate the construction and capability of blast equipment, the effect of furnace conditions.

In 2008, an iron smelting site dated to Liao Dynasty (AD 916--AD1165) was investigated at Shuiquangou in Yanqing county, which was located to the northwest of Beijing City. Some iron smelting furnaces with much slag and fractory were found. Among them, No.3 iron smelting furnace was well reserved, and its structure was clear. The section of the single-tuyere blast furnace has been reconstructed[1]154(Fig.1). According to historical literatures, the wood bellow was thought to be used in iron smelting in Central China, North Shanxi and Lower Yangtze River Vally in Song and Yuan Dynasty, so it might be also used in Shuiquangou iron smelting site [1]154-158.

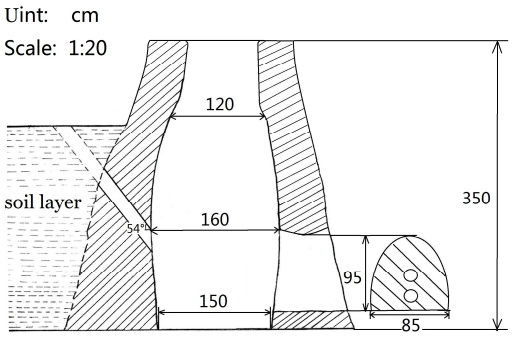

Fig.1 Section of the Reconstruction of No.3 blast furnace at Shuiquangou[1]

Based on historical documents and field survey, the wood bellow of No.3 furnace is reconstructed in this study. Its ultimate wind pressure and the speed of the wood bellow are estimated. The ventilate ability for its each portion is calculated respectively. The flow field in the furnace blasted with this wood bellow is simulated by the software FLUENT. In the end, the effect on the iron smelting techniques for single-tuyere blast furnace with this blast ability of the bellow is discussed.