# Explorations in the History of Machines and Mechanisms

# HISTORY OF MECHANISM AND MACHINE SCIENCE

Volume 15

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MARCO CECCARELLI

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# Explorations in the History of Machines and Mechanisms

Proceedings of HMM2012

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# Preface

The organization of an international symposium on the History of Machines and Mechanisms (HMM) every four years is the main activity of the Permanent Commission (PC) for the History of Mechanism and Machine Science of IFToMM, the International Federation for the Promotion of Mechanism and Machine Science. The first two symposia, HMM2000 and HMM2004 were held at the University of Cassino in Cassino, Italy in the years 2000 and 2004. The third symposium, HMM2008, was held at the National Cheng Kung University in Tainan, Taiwan in 2008. The present volume contains the proceedings of HMM2012, the 4th International Symposium on the History of Machines and Mechanisms that was held at VU University in Amsterdam, The Netherlands, from May 7 until May 11, 2012.

The mission of IFToMM is to promote research and development in the field of machines and mechanisms by theoretical and experimental methods, along with their practical applications. The aim of the international symposia on HMM is to maintain an international forum for the exploration of the history of machines and mechanism. Although the emphasis is on the history of technical systems and their applications, the scope of the symposia is wide. Relevant topics are also the history of theories and design methods, biographies, the history of the institutions involved, the relations with other disciplines, the history of engineering education and the social and cultural aspects of machines.

History is not only full of exciting and entertaining stories. Historical investigations put our own present day activities in a wider perspective. They help us define who we are. Moreover history remains a source of ideas.

This book is meant for researchers, graduate students, engineers and all others with an interest in the history of machines and mechanisms. We believe that it can inspire and motivate them.

After the review process 40 papers by authors representing 20 different countries were accepted for publication in the proceedings of HMM2012. One glance at the table of contents is enough to see that we succeeded in bringing together an interesting group of people with a stimulating variation in subjects. We are very satisfied with this result and we thank the authors for their valuable contributions and for the efforts in submitting the final versions of the papers in time.

We would like to express our sincere gratitude to the members of the scientific committee: Gerard Alberts (The Netherlands), Hanfried Kerle (Germany), Alexander Golovin (Russia) , Carlos Lopez-Cajùn (Mexico), Jammi S. Rao (India), Lu Zhen (P. R. China), Hong Sen Yan (Taiwan), Thomas Chondros (Greece; Chair of IFToMM's PC for History), Baichun Zhang (P. R. China). Moreover, we would also like to thank the colleagues who helped us in the review process: Jean Pierre Merlet, I-Ming Chen, Emilio Bautista, Juan Ignacio Cuadrado, Teresa Zielinska, Klaus Mauersberger, Agamenon Oliveira, Erwin Lovasz, Ton Klein Breteler, Burkhard Corves, Stephanos Paipetis, Just Herder, Vera Chinenova, John Gal, Pier Gabriele Molari, Junichi Takeno, Juan A. Carretero, Manfred Husty.

We also thank the sponsors of the symposium: IFToMM, the European Society for the History of Science, the Institute for History and Social Aspects of Science of VU University and the Department of Mathematics of the Faculty of Sciences of VU University. Moreover we are very grateful for the support we received from many friends and colleagues at the Faculty of Sciences: Saskia van Es, Cees van Gent, Dick Hoogendoorn, Hubertus Irth, Ger Koole, Frans van Lunteren, Ronald Meester, Andre Ran, Dirkje Schinkelshoek, Maryke Titawano. Without their support we would not have been able to organize HMM2012.

May 2012 — Teun Koetsier
Amsterdam — Marco Ceccarelli

# Introduction

Teun Koetsier

## Erewhon

In 1859 a young Englishman, Samuel Butler (1835-1902), immigrated to New Zealand. New Zealand was not an industrialized country, but England was. Shortly after 1800 Britain had become the first industrialized nation in the world. Machine based industry had replaced agriculture as the most important economic activity. The Industrial Revolution had begun in the textile industry, but soon moved to other areas of industry. Steam engines had been introduced. The iron industry grew and with it the coal industry. By 1850 most of England's areas were connected by railroads and in coastal and river transportation steamships had taken over. Butler had witnessed it. In New Zealand in 1863 he wrote a letter with the title "Darwin among the machines". He wrote:

> *"Day by day, however, the machines are gaining ground upon us; day by day we are becoming more subservient to them; more men are daily bound down as slaves to tend them, more men are daily devoting the energies of their whole lives to the development of mechanical life. The upshot is simply a question of time, but that the time will come when the machines will hold the real supremacy over the world and its inhabitants is what no person of a truly philosophic mind can for a moment question. Our opinion is that war to the death should be instantly proclaimed against them. Every machine of every sort should be destroyed by the well-wisher of his species."* (See [7])

Butler's memories of Britain together with his impressions of New Zealand stimulated his fantasy. In 1874 he anonymously published the novel called *Erewhon*. The word 'Erewhon' is an anagram of 'nowhere'. Erewhon is a country, somewhere hidden behind the mountains in New Zealand, where the inhabitants used to use machines but not anymore. The machines have all been destroyed together with all books on mechanics and all engineer's workshops in a war, the war between the machinists and the anti-machinists. The anti-machinists got the victory. After his arrival in Erewhon the protagonist of the novel learns about all this in the City of the Colleges of Unreason. Some machines survived the war, because of the intervention of the professors of inconsistency and evasion. These machines are studied in Erewhon in the way we study long forgotten religious practices.

In this fascinating novel machines are compared to a new life form that is evolving rapidly and threatens to become superior to man. It is argued that there are no good reasons to suppose that they cannot have consciousness. They have started to do things that are very similar to eating and talking. Moreover, they can reproduce. Of course, their reproduction is different from the way mankind reproduces itself. However, in nature there are many kinds of reproduction. The author of the *Book of the Machines* foresaw that the machines would enslave man in the distant future. In Erewhon this had not happened, but a war had been necessary to prevent it.

Butler's book nicely illustrates how the industrial revolutions were perceived in the 19$^{th}$ century. They were seen as revolutions in which machines became omnipresent in society. *Erewhon* is the first novel in which this technological development is taken as a central theme. The book is satirical, but also critical of the ubiquity of machines. Many similar stories would follow. In 1909 Edward Morgan Forster published a story in *The Oxford and Cambridge Review* called "The Machine Stops". In 1920 the Russian novelist Yevgeny Zamyatin wrote the novel *We*. In 1921 Karel Čapek wrote the play *R. U. R. (Rossum's Universal Robots)*. In 1926 Fritz Lang made the film *Metropolis*. Aldous Huxley's *Brave New World* (1932) and George Orwell's *1984* from 1949 were written in a similar vein. For an extensive list see [6]. Although many of such novels and movies reflect a romantic longing for a distant past that is usually idealized and often does not have much in common with the real past, they are great works of art that draw our attention to negative aspects and possible dangers of technological progress.

## The Escape from the Malthusian Trap

Of course, there is an entirely different way to look at the industrial revolutions. Instead of emphasizing possible downsides of the proliferation of machines one can also stress their positive effects. The *First Industrial Revolution* took place in the 18th century. In a sense it was the most striking development in the entire history of mankind. Economists sometimes say: The industrial revolutions made it possible for mankind to escape from the *Malthusian trap*. They mean this. Before the Industrial Revolution technology progressed – many examples of useful inventions can be given easily – but the standard of living of the average individual did not really change. Increases in the production of food were always followed by growth of the population leaving the average income per capita unchanged. Mankind was trapped. Yet the industrial revolutions changed it all. Mechanization in combination with the use of fossil fuels made such an increase of production possible that growth of the population could no longer neutralize it. Mankind had escaped from the trap.

Moreover, the First Industrial Revolution, dominated by textile machines, steam engines, iron, coal and the introduction of the factory system, was only the beginning. In the middle of the 19$^{th}$ century it was followed by a new wave of innovations: the *Second Industrial Revolution*. In this revolution railroads, steamships, steel, rubber and farm machines played the central role. The application of the steam engine to transportation had an enormous impact. Steam ships had been limited to coastal shipping because of the impossibility to bunker enough coal. The invention of much more efficient compound engines changed all this. Moreover in the iron industry finally one succeeded in producing steel cheaply. Some other industries emerged in addition to the railroads. The telegraph was invented by Samuel Morse and others. The electric dynamo made it possible to produce electricity. The transformer made long-distance transportation of electricity possible. Electricity could be used in industry. Charles Goodyear invented the process of vulcanization, which made rubber less sensitive to changes in temperature. It no longer became brittle in cold weather and sticky in hot weather. The petroleum industry got started and the chemical industry grew. Agriculture changed, because of new machines and fertilizers. In the industrializing nations production per capita rocketed.

With the First Industrial Revolution mankind seems to have entered an entirely new phase in its history. In the industrialized countries recurring waves of technological innovations pushed up production higher and higher. At the beginning of the $20^{th}$ century the *Third Industrial Revolution* took place. It involved automobiles, airplanes, electricity, radio, petroleum, movies. The economy and daily life were transformed by the automobile and by the use of electricity. This is the phase in which science began to play an important role in technology. The impact on the way wars were fought was also dramatic. The cavalry was replaced by tanks and aircraft began to play a role. The automobile industry and the aircraft industry received an immense stimulus. In 1938 the United States 3.600 airplanes were built. This number had become 96.000 in 1944 ([5], p. 199). The next wave came in the second half of the $20^{th}$ century when the *Fourth Industrial Revolution* took place: television, computers, plastics, the Internet and many of us wonder what the next industrial revolution will be like. Although Japan played an important role during the Fourth Industrial Revolution all four of them took place in the Western World. It is probable that in the *Fifth Industrial Revolution* Asian nations will dominate.

The escape from the Malthusian trap has considerably improved the lives of most people in the industrialized nations. And although as for the distribution of wealth worldwide there is much to be desired, technological progress is basically a good thing. This is fortunate because it happens to be an inevitable development. It is something we cannot escape from. It is the human way and if technology creates problems, we can only hope for good government and the development of more technology to solve them.

## Machines, the Science of Machines and IFTOMM

In everyday language a machine is an artifact that can be used to assist us in the execution of a specific task. This is a very broad definition. It covers simple tools like a hammer or a can opener, but also an airplane and a computer are machines in this sense. The definition may even be too broad. Is a frying pan a machine, are knitting needles machines? According to the Dictionary [1] of IFToMM , the *International Federation for the Promotion of Mechanism and Machine Science*, a machine is a technical system "built to transform energy or matter or to transfer and transform movement and force in accordance with certain control information" (Translated from the German: "zum Umformen von Energie oder Stoff oder zum Weiterleiten und Umformen von Bewegung und Kraft gemäß zugeführten Steuerinformationen"). IFToMM's definition refers to traditional machines, the machines that dominated during the first two industrial revolutions and continued to play a central role during the revolutions that followed. In IFToMM mechanisms are "constrained system of bodies designed to convert motions of, and forces on, one or several bodies into motions of, and forces on, the remaining bodies". Often, mechanisms are parts of machines. It is not unusual that in a big machine many different mechanisms can be distinguished.

Although attempts to understand and design machines and mechanisms on a scientific basis go back to antiquity, scientific mechanical engineering as an established discipline of great practical importance must be associated with the Third Industrial Revolution. Scientific mechanical engineering was born when mechanical engineers discovered the value of a scientific approach. This started on the continent in Europe with sophisticated and often graphical methods that were used in the design of mechanisms. It took some time before these methods spread to the US. Once they had established themselves there, after World War II they were replaced with the introduction of electronic computers in the 1960s by analytical methods. This led to extremely fertile research programs in mechanism and machine science.

One might have the impression that only during the first and the second industrial revolutions machines played a central role. That impression is wrong. Many machines have become less visible. They have become smaller and less noisy. They have also become more autonomous, needing less people to control them. Moreover, we got very much used to them. Yet, in industry, in construction works, in transportation, in agriculture, in the army, in hospitals and at home, machines are everywhere. Although one does not immediately associate the new technologies in the second half of the 20$^{th}$ century with them, machines and mechanisms continued to play a central role in our interaction with nature. Machines were and are one of the pillars of modern scientific technology and they are, moreover, from an intellectual and engineering point of view challenging. So it is not strange that the Fourth Industrial Revolution was accompanied by considerable interest in the theory of machines and mechanisms. The birth of IFToMM as part of the Fourth Industrial Revolution wasn't accidental.

In 1969 engineers from behind the Iron Curtain, the Western World and some crucial non-aligned countries, got together and founded IFToMM. This is remarkable. IFToMM was founded in the middle of the Cold War. In the 1970s, I had the pleasure of meeting a vice president of a major American aircraft industry. This gentleman by the name of Barton Evans told me he had worked for the CIA in the 1950s and 1960s contacting American scientists who were going to be or had been in touch with colleagues from communist countries. He proudly showed me his copy of *Who is Who in CIA*, a booklet prepared in 1966 and published in 1969 by the Department of Disinformation in Czechoslovakia in order to make life for the CIA harder ([2] and [3]). The name of my CIA agent was in the booklet. Although Evans had not been involved he was sure that the foundation of IFToMM had been surrounded by considerable CIA and KGB interest and briefing and debriefing from all sides. Right from the start IFToMM was in every respect an international organization. The USSR, Bulgaria, the German Democratic Republic, Hungary, Poland and Rumania represented Eastern Europe. The West was represented by the USA, Australia, the German Federal Republic, Italy and the United Kingdom. India and Yugoslavia were the non-aligned countries. On the other hand, big parts of the World were not represented. Right now IFToMM has 48 member organizations. The Ibero-American community is represented and so is Asia. The organization has grown but, inevitably, it has also changed its focus. In the 1960s, for example, classical kinematics of mechanisms remained a core discipline. In the past 50 years fast computing, sophisticated software and new applications have changed the theory of machines and mechanisms. Mechanical engineering has always been a multidisciplinary activity, but the number of disciplines involved has only grown. Kinematics, dynamics and gearing are classical subjects but the computer has changed them. We now have, for example, computational kinematics, multibody-dynamics and tribology. Really new subjects are robotics, mechatronics and micromachines.

## IFTOMM'S Permanent Commission for History

The history of Mechanism and Machine Science is part of the history of science and technology. The word *technology* was coined by the German Johann Beckmann (1739-1811). He used it for a description and classification of all the existing crafts and methods of manufacture. The 1971 edition of *Webster's Third International Dictionary* says that technology is "The science of the application of knowledge to practical purposes". Definitions and distinctions are useful. However, it is difficult to draw a sharp border line between practical problems and non-practical problems. Basically a practical problem is a problem that requires some action outside of the study or the laboratory. In this context it makes sense to distinguish *knowledge-how* from *knowledge-that*. *Knowledge-how* is related to functionality; it concerns what should be done to reach some goal. We know how to get somewhere, how to do something, sometimes without even knowing why the method works. *That is knowledge-how*. Technology is or concerns always *knowledge-how*. *Knowledge-that* is related to truth; we know that something is the case, nothing more, nothing less. It may be completely useless. Pure science is *knowledge-that*. It is the multidisciplinary character of Mechanism and Machine Science in combination with the fact that it encompasses both knowledge-that and knowledge-how, which has led to a situation in which the history of machines and mechanisms and the scientific theories related to them is not often studied in its own right. Obviously historians of science are interested in the history of machines, but usually only in so far as it concerns mathematics, physics or one of the other sciences. On the other hand, historians of technology tend to concentrate on what machines can do and discuss their economic, social and cultural impact. Although such work is very valuable, the focus is usually not on machines and mechanisms in its own right. That is where IFToMM's Permanent Commission (PC) for History is filling a gap. The commission was established in 1973 because of the strong support from the first IFToMM President, the impressive Ivan I. Artobolevskii from Russia. In the PC for History almost all nations participating in IFToMM are represented. In the course of time the PC has been chaired by Jack Phillips (Australia), Elisabeth Filemon (Hungary), Teun Koetsier (The Netherlands), Marco Ceccarelli (Italy), Hong Sen-Yan (Taiwan) and Hanfried Kerle (Germany). The present chair is Thomas Chondros (Greece).

Originally the PC primarily dealt with the institutional history of IFToMM but in the course of time it broadened its scope. Now, the activities of the commission cover all aspects of the history of machines and mechanisms and the theories dealing with them. I think this is a very good thing. Given the central role of machines and mechanisms in the development of technology their history indeed deserves special attention.

## This Volume

The 38 chapters of this volume nicely illustrate the activities of IFToMM's PC for History. Most of the authors are engineers and not professional historians. Modern professional historians of science and technology put great emphasis upon understanding the actual historical development, while many of the authors in this volume deal with what is sometimes called "heritage": they look at the past as modern engineers. What happened in the past from an engineering point of view? is for them the central question. That in itself leads to very interesting results. It leads, for example, to the possibility of a modern analysis of an ancient machine or the application of modern design methodology to answer the question what kind of machine could have been built in the past.

It is interesting to view the contributions in this book against the background of the big history of mankind. In his extremely well written *Why the West Rules – For Now* [4] Stanford historian Ian Morris describes the history of mankind as a race between the East and the West. After the last Ice Age the so-called "Hilly Flanks" in an arc shaped area covering parts of Iran, Turkey, Syria and Israel was in an extremely favorable position. By 10.000 BC the possibility of the domestication of plants and animals had been discovered there. The cereals that would develop into wheat and barley grew there abundantly and the climate was suitable for agriculture. The West, defined broadly by Morris, took the lead. The East followed two thousand years later. In both the East and the West social development took place along similar lines. In the course of time big agricultural empires developed. A major step forward was the transition from kingdoms that functioned on the basis of relations between the members of the elite to so-called high-end states in which taxes were raised and professional bureaucrats and soldiers represented the state. In this respect the Roman Empire in the West can be compare to the empire of Qin Chi Huang Ti, the emperor whose grave in Xi'an is protected by the well known army of terracotta warriors. Rome started as a city in Italy and became a superpower in the 2$^{nd}$ century BC. Qin was a small Chinese state, but it conquered its last enemy in 221 BC. At the time the West went ahead as for social development. However, in the last centuries of its existence the Roman Empire entered a period of decline which created an opportunity for the East. Things were different in the East. In the 6$^{th}$ century the East took over the West. When Marco Polo visited China in the 13$^{th}$ century everything about China amazed him: in many respects he faced a superior civilization. This supremacy would last until the 18$^{th}$ century when in the West the First Industrial Revolution started. The West bounced back and in the 19$^{th}$ century it took over most of the world.

Yet, as we know, in the 20th century things started changing. The West still rules. For how long, however? Morris argues that in order to understand social development in the past and in the future geography is a crucial factor. The domestication of plants can only be discovered if the geographical circumstances are favorable. Morris explains the fact that the Industrial Revolution took place in the West and not in the East also in terms of geography: the West was favorably positioned in order to discover America, which had in many different ways an enormous impact, Together with other geographic factors like the availability of coal in England this led to the First Industrial Revolution.

The present volume on the history of machines and mechanisms consists of six sections. In Section I the emphasis is on the role of institutions. Section II is devoted to primarily biographical contributions. The Sections III, IV and V are on mechanical systems. Section VI is devoted to papers on concepts and theories. If we consider the book against the background of Morris' big history, most of the 38 chapters in this book are understandably clearly directly related to developments in the West. They concern the industrialized nations in the 19th and 20th centuries. There are, for example, contributions on the history of MMS in German, Russia, Spain, France Italy, Romania, Mexico, Serbia and England. Yet several contributions refer to the wider context. Kuo Hung-Hsiao and Hong Sen-Yan apply a modern design methodology to an ancient Chinese cross bow. Section II starts with a paper by Nam Moon-Hyon that nicely illustrates the technological potential of the East in the 15th century. He discusses the Korean Chief Royal Engineer Jang Yeong-sil, who designed a complex water clock.

Several chapters in the book are devoted to Greek and Roman culture. In section III Finlay McCourt studies mechanisms of movement in Heron of Alexandria's work. In this same section Junich Takeno and Yoshihiko Takeno attempt to unravel the mystery of the defense chain that once protected Constantinople. Section IV starts with a paper by Michael Wright on the Antikythera mechanism, an unbelievably complex planetarium from the second century BC. In the last section Giuseppe Boscarino compares the epistemological status of concepts in Aristotle and Archimedes. Such papers demonstrate unique aspects of Western culture. The East never developed anything comparable to Greek mathematics and astronomy. This is a significant point. Could the first industrial revolution have taken place in the East? Morris argues that in the 11th and 12th centuries such a revolution was brewing in Kaifeng, at the time a very big and prosperous city. Momentous changes took place there, in the textile industry, in coal and in iron works. Yet, the development didn't continue. In the 15th century huge Chinese Treasure Fleets explored the Indian Ocean, but they did not cross the Pacific; geographically China was positioned less favorably with respect to the Americas than Europe. At certain moments China consciously rejected Western culture. In section I Michela Cigola describes the role of the Jesuits in the spreading of mechanical knowledge from Europe to China in the 16th and 17th centuries. That is the period in which the East was still superior. In some respects Jesuit astronomical knowledge was clearly superior to Chinese astronomical knowledge, but the Chinese emperor felt he did not need Western science.

One of the crucial elements in Western culture that did not have its Chinese counterpart is the clockwork model of nature. Western philosophers like Descartes realized that it was not necessary to consider nature as a living organism. One could view it as a machine and understand its functioning from this extremely fertile point of view. Several chapters in this book are on the Western tradition of automata and clocks. The clockwork model of nature was a crucial element in the Scientific Revolution in the West and is clearly linked to the development of mathematics during and after the Renaissance. Western culture had at the time one great asset that the East did not have: the Greek scientific heritage. The question why the Industrial Revolution did take place in the West and not in China is not a simple one. Geographic factors were certainly important – Morris is right there - but it seems highly probable that essential elements in the Western cultural tradition, that go back to the Greeks and include a theoretic interest in machines, also played a role. At this point the work of Margaret Jacob must be mentioned. See [8]. She did show how the Scientific Revolution, which was influenced decisively by Greek culture, had in its turn a cultural impact that in a subtle way contributed to the First Industrial Revolution.

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