# Theory of Conjugate Surfaces and Its Applications

# 共轭曲面原理及其应用

## ——陈志新论文集

Collected Scientific Works of Chih-Hsin Chen

陈志新◎著

中国科学技术出版社

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·北 京·

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# Biography

Chih-Hsin Chen (Chen Zhixin) was born in Cixi, Shaoxing County, Zhejiang Province in 1931 and moved to Shanghai in 1937. He was enrolled in Tsinghua University in Beijing in the autumn of 1949 and graduated in August 1952. After graduation, he worked as an engineer in China FAW Group Corporation. To support national defense modernization program, he joined Harbin Military Engineering Institute as a lecturer in May 1955 and was promoted to the rank of Captain in 1956. In January 1961 he was transferred to Xi' an Armored Force Engineering Institute as a lecturer and was promoted to the rank of Major in 1962. He later was promoted again as an Associate Professor in April 1963. In August 1970 he was transferred to Beijing Institute of Armored Force Technology as a Senior Researcher. In March 1980 he was conferred as Professor in Shanghai University of Technology and served the director of research center of Theory of Conjugate Surfaces. In 1994 he retired from the university but still devoted himself to the study of the "Theory of Conjugate Surfaces" and its applications to numerous technical fields: gearings, theory of mechanisms, analysis and design of innovative mechanisms (bio-like robots) with multipoint conjugation joints, motion interpolation for numerical machining and animation, multi-body system dynamics/conjugato-elasto-dynamics and surface interpolation of computation graphics. He continued to write and publish technical papers after his retirement as a private researcher and consultant until he suffered from a stroke in October 2005.

Since 1955, Chen had initiated and developed the "Theory of Conjugate Surfaces". After more than 50 years of dedication and effort, he managed to make great achievements and has thus far published 5 academic monographs and more than 60 scientific articles. The five monographs are "Theory of Conjugate Surfaces Vol. Ⅰ" (1974), "Theory of Conjugate Surfaces Vol. Ⅱ" (1977), "Rotation of Vector & Engineering Differential Geometry" (1982), "Kinematics of Conjugate Motion & Geometry of Conjugate Configurations" (1982), "Fundamentals of the Theory of Conjugate Surfaces" (1985). Some of the leading papers are "Theory of Continuously Contact Conjugate Surfaces and Its Applications" (1956), "Motion Interpolation Based on Rotation-of-Vector Methodology and Its Application in NC Machining" (1998), "Interdependencies Between Contact Traces In A Multi-Point-Conjugation Joint" (2000) etc.

In January 1978, Chen was awarded the "Outstanding Scientific and Technological Worker", the "First Class Merit Award", 3 times for the "Third Class Merit Award" and the "Order Award" by Armor command of CPLA (Chinese People's Liberation Army) for his great achievements in the design of transmission system, control system and a suspension system for the CPLA self-designed armored personnel carrier and main-battle tank. And again he was awarded the

"Advanced Worker" by the National Science Conference in 1978.

In recognition of Chen's independent innovation and achievement in the "Theory of Conjugate Surfaces", he was awarded the "Science & Technology Advancement Award" by China National Education Commission in 1986 and the "National Natural Science Award" by China National Science and Technology Commission in 1987 respectively.

Chen had been elected as a delegate of National People's Congress from 1978 to 1983, and as a delegate of Shanghai People's Congress from 1983 to 1988.

After the culture revolution and opening up of China, Chen was invited to attend and participate in numerous international conferences and academic exchanges in Europe, USA and Japan. He has been a member of ASME since 1980, a member of IEEE since 1998 and a member of ACM since 1998. He was also selected in Marquis Who's Who, ABI and IBC of more than 10 national and international biographies. ABI awarded him the "Most Admired Man of the Decade" (1995) and "Men's Inner Circle of Achievement" (1996). IBC awarded him "Twentieth Century Award for Achievement" (1998). In February 2001, he was elected as an ASME Fellow.

Twentieth Century

Achievement Award

The Board of Directors of the
American Biographical Institute
sitting in the United States of America
recognizes

Prof. Chih-Hsin Chen

as most admirable and
whose career achievements and social contributions
have been selected for permanent documentation in
Five Hundred Leaders of Influence
designed for biographical reference and
inspiration for present-day citizens of the
Twentieth Century as well as future generations.

Registrar

Original Volume of
Five Hundred Leaders of Influence
on Permanent Record and Display at the
U.S. Library of Congress, Washington, D.C.
Publication Date: 1997

美国传记协会（ABI）授予“20世纪成就奖”

入选“国际500名最具影响力的领袖人物”（1997）

ASME INTERNATIONAL

The American Society of Mechanical Engineers

Founded 1880

By action of the Board of Governors has elected

*Chih-hsin Chen*

**Fellow**

and is entitled to all the privileges granted by the Constitution
of the Society, an organization for promoting the art,
science, and practice of mechanical engineering

**February, 2001**

President

Executive Director

推选为美国机械工程师学会

“ASME Fellow”（2001）

# 序　言

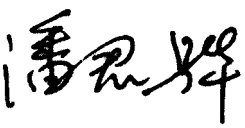
陈志新教授是我们1949年进入清华大学机械系的同班同学。共同学习不久，大家就知道他的学业很强，很钻研，他的数学根底很好，在高中时就自学了微积分。他为人很随和，很真诚，因此得到全班绝大多数同学的尊敬。他会将学到的知识立即用到实践中去，记得有一年过元旦，大家动手做一个利用电灯泡产生热气流推动的走马灯，他就用数学方法求解纸做的叶片扭转的最佳角度，给我留下深刻印象并受益匪浅。还有一次，教机械原理的老师留下一道未解的题目：证明万向联轴节被动轴的转速是不均匀的，它和两轴夹角有关。结果，只有陈志新和另外一个同学邱焘求得了证明。这些事情，我印象深刻，一直没有忘记，同时也学到了他们良好的求知态度。毕业以后，我分配到科学院系统，并不久又改光学专业，和他没有联系。一直到80年代，我调到中科院南京天文仪器研制中心，有一位搞齿轮设计的同事，向我打听陈志新的地址，想请教关于共轭曲面的问题。我往西安发了一封信，但被退回，因为他那时已到上海去了。不过，由此事我知道陈志新在钻研共轭曲面，并已相当有名气。到了90年代中期，老同学之间，开始有了较多联系，我才知道陈志新开创了共轭曲面这门新学科，并获得了国际同行的公认。前些年，我很想推荐他为中国工程院院士，收集了一些材料，可惜因为隔了学部，使不上劲。收集到的材料中，有一位当时在香港中文大学做访问的学者向美国机械工程师学会(ASME)推荐陈志新为ASME的Fellow的信，其中写道："……陈教授在发展共轭曲面理论方面的成就在ASME机构学的社区里，是众所周知的(Professor Chen's achievement in the Theory of Conjugate Surfaces is widely known in ASME Mechanisms community)"，还写道："Professor Chen represents the best of an engineering professor, with a wonderful combination of extensive practical experience, exceptional research work, and educational leadership. He also been a member of ASME for twenty years. The electing of Professor Chen's ASME membership to Fellow Grade is well deserved and long overdue."这样高的评价，在一般的推荐信中是较少见的。

陈志新在写了三本专著之后，继续写出多篇论文，发表在各种学术刊物上，都是有关共轭曲面的。他现在患脑中风之后，虽然神志清醒，但基本上丧失了

语言功能，且行动困难，我们从他家人那里知道，陈志新有一件心事，就是把后期的那些文章集合起来出个文集，以便后人查阅和研究共轭曲面之用。这件事，现在他自己已无法完成。有一次，几个老同学去看望他之后，产生大家来帮他做这件事的想法，很快取得一致意见。经过一段时间的准备，现在终于实现了。

根据另一位境外学者的介绍，我知道陈志新开创的共轭曲面理论对于共轭运动和工程微分几何的进展，作出了重要贡献。在此理论基础上，他开创地研究多点共轭和共轭—弹性—动力学(CED)，对于生物/类生物机构学的发展有着深远影响。再有，由共轭曲面理论发展出来的旋转向量方法论，对于运动内插方法的进展也有重要贡献，而运动内插方法是和等价的低副虚拟机构的设计在概念上是紧密相连的。

我们衷心祝愿陈志新学兄身体能早日康复，也希望他开创的这门新兴工程学科在国内后继有人并得到应有的评价，这是我们老同学们共同做这件事的唯一目的。



(中国工程院院士)2007 年 10 月

# Preface

Professor Chih-Hsin Chen is our classmate, who was enrolled in the Department of Mechanical Engineering, Tsinghua University, China, in 1949. Not long after that, we got to know his intelligence and diligence. He had good mathematic foundation because he spent his spare time studying Calculus since his high school days. Due to his gentle and honest personality, he was very much admired. He always applied what he learned into practice. I still remember that during one of the New Year days in the university, we made a lantern rotated by the heat from lamp bulb, he designed the paper turbine with the optimized angle based on his mathematic calculation. I also remember that our lecturer of Mechanism course (Machine Theory) gave us a paper exercise to prove that "rotating speed of universal coupling driven shaft is not uniform due to the included angle between the two axes". It was Mr. Chen and another classmate Qiu Tao who managed to prove it. All these anecdotes have left us with a very deep impression. After graduation, we were dispatched to different organizations. I worked in the Chinese Academy of Sciences and was diverted into optical research area. We did not contact each other until the 80's. After I transferred to Nanjing Astronomical Instrument Research Center, one of my colleagues approached me to find out more about Dr. Chen's "Theory of Conjugate Surfaces". I wrote a letter to him to Xi'an, but I couldn't reach him as later I learnt that he had already moved to Shanghai. However I knew that he was studying on the "Theory of Conjugate Surfaces". From the 90's, through alumni affiliation, I knew that Dr. Chen had developed the "Theory of Conjugate Surfaces", and his achievement was widely known in the international academic society. Years ago, I intended to nominate him to be a member of the Chinese Academy of Engineering, and collected some information. But due to the fact that we were in different branches, the submitting process did not get through. In my collected documents, one of the recommended letter of thescholar for nominating ASME Fellow gave him very high appraise, "Professor Chen's achievement in the 'Theory of Conjugate Surfaces' is widely know in ASME Mechanisms community" and "Professor Chen represents the best of an engineering professor, with a wonderful combination of extensive practical experience, exceptional research work, and educational leadership. He also has been a member of ASME for twenty years. The electing of Professor Chen's ASME membership to Fellow Grade is well deserved and long overdue".

After Dr. Chen published 3 academic monographs, he still devoted himself to the research work and published numerical technical papers in the "Theory of Conjugate Surfaces" until he suffered from a stroke. We, as old classmates, hope that his "Theory of Conjugate Surfaces" and its applications would be further explored and referenced by successors. We came up with a pro-

posal to publish his technical papers on the "Theory of Conjugate Surfaces". Now the book is being published through everyone's effort.

Base on one of the oversea scholar's recommendations, I further understand that Dr. Chen had initiated and developed the Theory of Conjugate Surface, he had made important contribution to the advancement in Kinematics and geometry, i. e., Conjugate Motion and Engineering Differential Geometry. Based on this theory, he initiated the investigations of multi-point conjugation and conjugato-elasto-dynamics (CED), which yield profound impacts on the development of the theory of bio/bio-like mechanism. Meanwhile, the rotation-of-vector methodology, developed in the Theory of Conjugate Surface, makes important contribution to the advancement of motion interpolation, i. e. motion interpolation is conceptually interconnected with the design of equivalent virtual mechanisms of lower-pairs.

As his classmate, we hope that Dr. Chen will recover earlier as ever. Our only intention to publish this book is to see that his innovative engineering science will have successor and is being widely recognized.

**Pan Junhua**

Academician of Chinese Academy of Engineering

2007. 10

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## 第一部分　中文论文



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* 本论文集因搜集的论文时间跨度较大(1955～2008 年),故名词术语、计量单位等均以原出版时为准,未作统一性改动。——编者注

## 第二部分　英文论文

## 第三部分　附录

# 第一部分

# 中文论文

# 关于“外啮合螺旋齿轮和人字齿轮指状铣刀轮廓的求法”一文的商榷

陈志新

本刊第五卷第十一期(1954 年 11 月)中刊载的“外啮合螺旋齿轮和人字齿轮指状铣刀轮廓的求法”一文(陈震同志译自 A. H. Грубин 等著的“齿轮刀具”),个人认为其中在推导计算公式的方法中有原则性的错误,因此其所获得的结果亦是不正确的。显然地,利用这样的公式来求指状铣刀的轮廓,其所求得的形状亦不可能是正确的了。现将个人的意见发表在下面,作为同志们的参考。

## 一、错误的实质

在译文中推导渐伸线螺旋齿轮侧面方程式时,所用的方法为解析一图解混合法,当然与纯解析法相较,是没有后者来得具有说服力量和简短扼要,但其所得的结果还是正确的。即是:

$$\left.\begin{aligned} x &= r_0(\varphi-\varphi_x)\cot\beta_0 \\ \Omega &= \varphi+\delta_0 \\ y &= r_0(\varphi_x\sin\Omega+\cos\Omega) \\ z &= r_0(\sin\Omega-\varphi_x\cos\Omega) \end{aligned}\right\}\text{原公式(1)~(4)}$$

但原文的作者虽然明确了这些是参数方程式,但对其中的独立参变数的认识是不足的。显然地,在上述四个相互独立的方程式中,一共有着六个变数,即 $x$、$y$、$z$、$\Omega$、$\varphi$、$\varphi_x$;因此其中必有两个而且只有两个是独立参变数。至于究竟选哪两个作为独立参变数,那完全可以由我们自己任意选定。

正因为上述四个方程式中有着两个而且只有两个独立参变数,因此它才代表着一个两维空间的曲面。明确了这一点之后,就很明显地可以得出这样一个结论:即当我们令 $y$ = 某一常数时,这就去除了一个独立参变数,而只剩下一个独立参变数了。当然在除 $y$ 外剩下的五个变数中到底挑哪个作为剩下的一个独立参变数是任意的。但问题的关键在于只剩下一个而不是还有两个独立变数了。既然是这样,那么可以知道在译文的方程式(9)之展开式中,即在

$$\begin{aligned} R_{\text{н}}^2 &= x^2+z^2 \\ &= x^2(1+\tan^2\beta_0\cos^2\Omega)+2r_0\tan\beta_0\cos\Omega(\sin\Omega-\varphi\cos\Omega)x+r_0^2(\sin\Omega-\varphi\cos\Omega)^2 \end{aligned}$$

之中,$x$、$\Omega$ 不可能再互为独立参变数了(因已在 $y$ = 常数的条件下)。其中只可能有一个独立变数,另一个只能为它的互变数。换句话说,就是 $R_{\text{н}}^2$ 并不是 $x$ 的一个简单的两次多项函