第十二届全国设备监测与诊断学术会议论文集

设备监测与诊断技术及其应用

中国机械工程学会设备与维修工程分会　编

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前　言

科学技术的进步将人类社会推向了信息时代。设备监测与诊断的主要目的是利用运行设备所表现出的各种有效信息，全面地分析其当前的状态，有效地诊断故障类型和部位，科学地预测设备状态发展及维修时间；设备检测与诊断技术的深入研究和广泛的工程应用实践，为现代维修方式的发展奠定了基础。

设备检测与故障诊断技术的研究与发展大体可以分为三个方面：一是综合传感技术、测试技术、信号处理技术和微计算机技术的检测诊断仪器，为设备检测与故障诊断工作的开展奠定了坚实的基础；二是以现代人工智能为代表的检测与分析方法的研究和探索，为设备检测与故障诊断的智能化提供了可能；三是设备维修体系改革的探讨与工程实践，推动了设备检测与设备故障诊断技术的发展。

近年来，设备监测与诊断技术的发展，在我国经济建设中发挥着重要作用。为开展学术研究，促进设备监测与诊断技术在企业中的广泛应用，总结交流经验，推动本领域有关技术的探入研究和实际应用。中国机械工程学会设备与维修工程分会于2005年11月于海南省组织召开了第十二届全国设备监测与诊断学术会议。该学术会议的主题为：探索设备监测与诊断的科学发展观，交流现场设备监测与诊断的实用经验，介绍国内外设备监测与诊断的创新技术，推荐设备监测与诊断的典型案例。

本届学术会议交流的内容包括：论述设备监测与诊断技术的新进展及发展趋势；介绍设备监测、诊断和维护技术的有关新理论、新方法、新经验；交流设备监测与诊断工程的应用技术及取得的经济社会效益；面向机电设备的简易有效的状态监测和故障诊断方法；智能监测、诊断、预测及智能维护技术及应用；振动、声监测与诊断技术及应用；油液监测与诊断技术及应用；电气监测与诊断技术及应用；无损检测与诊断技术及应用；红外检测与诊断技术及应用；新型监测与诊断仪器及系统；基于网络的监测与诊断技术；基于虚拟仪器的监测与诊断技术；设备监测与诊断技术中的信息集成与融合；模糊诊断、小波分析、神经网络、基于知识的专家系统；非平稳、非线性、非高斯信号的处理和分析技术；大型机电设备状态监测、诊断及预测技术及应用；通过设备监测与

诊断技术，实行预知维修和主动维修的经验、效益；设备监测、故障诊断及趋势预测的评判标准及方法；国内外设备监测和诊断仪器的开发研制、质量控制、售后服务、用户反馈情况和经验；用户对国内外设备监测与诊断仪器的分析和评价；其它监测与诊断技术及工程应用等。

本届学术会议得到了各级领导的大力支持，尤其是广大学者和专业技术人员的积极参与。参加本届学术会议和撰写学术论文的有国外知名专家，本领域德高望重的院士，以及300多位学者、专家和工程技术人员。会议围绕设备维修体系、现代检测与诊断方法、新型仪器仪表尤其是虚拟仪器技术、以及广泛的工程实践研究等内容进行了广泛的交流；其特点是结合生产实际，强调应用推广。采用的论文形式从设备维修体系探讨、检测诊断原理和方法研究、先进仪器开发，到广泛的工程实践，进行了多角度、多层面的讨论；研究和应用成果涉及机械、石油、石化、冶金、化工、轻工、铁路、航运、航天、材料和仪器仪表等20余个行业，来自高等院校、研究院所、企事业单位和仪器研发厂家40余家。

为了体现近几年来设备监测与诊断技术的研究与实践，展示我国现阶段本领域的现状与发展。将本届学术会议的有关论文编撰成专业书籍，本专业书分为以下几个篇目：故障诊断技术体系与发展；现代故障诊断的原理与方法；振动监测与故障诊断；油液监测与故障诊断；虚拟仪器技术及其应用；设备故障诊断技术在工程实践中的应用。

本专业书是在编委会和论文作者的共同努力下完成的，借此机会对参与本书撰写、编辑和出版工作的有关单位和人员表示衷心的感谢；同时向关心我国设备监测与诊断技术的研究、应用和推广工作的各界人士表示崇高敬意。

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《设备监测与诊断技术及其应用》编委会

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第一篇

特邀论文

COMADEM: A Proactive Integrated Multidiscipline for the 21st Century

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Abstract: Rapid changes in the fields of science, engineering, technology and management on a global scale are taking place. As a consequence of this great challenges are emerging to be urgently addressed by educators, professional/R & D organisations, government bodies and industrial communities worldwide. **CO**ndition **M**onitoring **A**nd **D**iagnostic **E**ngineering **M**anagement (**COMADEM**) is a fast-emerging proactive multidiscipline, which addresses important current global issues in engineering education and training at all levels. Since its inception in 1988, the philosophical and the practical aspects of COMADEM have been widely propagated to the academic, professional and industrial communities worldwide. This has resulted in the establishment of various undergraduate/postgraduate/doctoral/funded research/development programmes worldwide. Through such dynamic programmes, difficult solutions to a number of problems have been proactively and profitably resolved by implementing novel, innovative and cost-effective hardware/software. The technical literature in terms of patents, doctoral thesis, undergraduate/postgraduate research reports, textbooks/handbooks/conference proceedings and journal papers (both refereed and commercial) are profusely growing at an exponential rate. This trend is growing unabated. A number of annual/biennial international conferences and exhibitions are now organised in different parts of the world focusing on various aspects of this interdiscipline. Successful and continued efforts are being made to reinforce/explore/exploit the positive virtues of this multidiscipline for maximum benefits through international academic/industrial collaborative/partnership schemes. This paper will present the accumulated research findings, valuable experiences gained and to reflect some thoughts into the future of engineering education and training. A change of culture in engineering education and training worldwide is stressed to produce a high quality, well-rounded and valuable human asset to proactively and intelligently manage our limited global resources for the good of the mankind.

Keywords: COMDEM; Condition Monitoring; Diagnostic Engineering; Proactive Management; Forensic Engineering; Asset Management; Engineering Education; Engineering Training; Maintenance Engineering; Maintenance Management; Technology Management; Engineering Management.

Introduction

The famous Chinese philosopher Confucius once said 'Man has three ways of learning: Firstly, by medication, this is the noblest. Secondly, by imitation, this is the easiest. Thirdly, by experience, this is the bitterest'.

20th century witnessed a number of sea changes in major fields of science, engineering, management, medicine, politics, business, socio-economic and human factors in engineering. These mega changes have no doubt brought immense benefits and have improved our quality of life in general. At the same time we should not take comfort and ignore the many problems associated with it. While the immediate benefits are obvious and exciting, there lurks a number of potential risks and problem areas to be identified, proactively monitored, diagnosed, prognosed and effectively controlled in major disciplines of health and safety, quality and reliability, energy and environment, global economy and communication, nanosciences and biotechnology, materials and manufacturing engineering, human factors, security and terrorism, etc. What we now need is a culture change. The most effective and sensible approach is to focus on the most dynamic and competitive knowledge-based economy. This means encouraging and nurturing intelligent knowledge discovery, generation and dissemination through effective and collaborative networking and communication at all levels and with minimum delay.

What is COMADEM?

COMADEM is an acronym for **CO**ndition **M**onitoring **A**nd **D**iagnostic **E**ngineering **M**anagement. It is a multidisciplinary-based, proactive, technology management discipline aimed to prevent any impending/incipient critical failures of various systems and thus reduce or eliminate the consequences of failure to an absolute minimum by employing the available smart tools, techniques, knowledge and strategies effectively and efficiently. The author pioneered this concept in the late 1980s when the economic performance of the UK was on the downward slope.

Why COMADEM?

The general economic scene in many advanced countries during 1970s and 1980s suffered a lot due to poor industrial performance, industrial unrest, and rapid changes in the socio-economic systems. Due to political changes the national boundaries were changing fast with its attendant problems. At the same time advanced scientific and technological discoveries/inventions were changing the very foundations of the human behaviour. This in turn was providing the impetus to customer freedom to demand the quality of goods and services to their exacting standards/requirements at a competitive price when and where it was needed. This trend was accelerated with the revolutionary changes in the information technology, manufacturing technology, materials technology and modern high-speed transport systems. Mobility of goods/services/technology transfer/sub-contracting and human mobility was on the increase. There were increasing pressures on all aspects of the economic activities to continuously improve the performance of all national assets (both physical and human) as quickly as possible. Governments, business/industrial sectors & educational sectors were engaged in encouraging, promoting and assisting their communities with novel/innovative/entrepreneurial/collaborative/partnership/joint technology initiatives under the knowledge engineering and management initiatives/programmes. As the systems were becoming sophisticated and complex in nature, there were increasing instances of system/product failures/accidents due to poor/dangerous main-

tenance practices, poor health and safety standards, poor quality and reliability of goods and services, lack of proper education and training programmes in managing the national assets and inadequate support to strengthen the excellence in scientific and technological research and development activities. Solving such complex issues required multidisciplinary and proactive approach rather than treating the solution as a quick fix piecemeal and isolated issue. The time was just right to explore and exploit a novel and innovative way to develop a proactive industry relevance knowledge base to tackle fast emerging unfamiliar problem areas.

A Brief Historical Background to COMADEM Interdiscipline

(A) Contributions to Higher Education

In 1986 – 87, the author published his first paper entitled Educational Needs in Condition Monitoring and Diagnostic Engineering Management (COMADEM) in the Journal of Measurement & Control. It was during this time novel and innovative undergraduate programmes were successfully developed on COMADEM discipline and reported in the International Federation of Automatic Control (IFAC) Symposium on Trends in Control & Measurement Education held in Swansea, UK in 1988. In the 1990s a new and novel postgraduate diploma in Systems Monitoring and Diagnosis was successfully developed. This programme was then redesigned and successfully ran as an MSc Full-time/Part-time programme in Condition Monitoring. The author stressed the need to develop National Vocational Qualification (NVQ) in Condition-based Maintenance Technology Management. He actively participated in developing various postgraduate programmes in Maintenance and Asset Management programmes at a number of UK universities. As an invited external examiner/external Lecturer/visiting professor for a number of universities in the UK, India, Canada, Republic of South Africa, Sweden, Finland, Nepal, and Middle Eastern countries the author has relentlessly continued his quest to introduce and develop industry-academy relevant undergraduate/postgraduate/doctoral/training programmes in this integrated proactive multidiscipline.

(B) COMADEM International Congresses & Exhibitions

The first successful international congress and exhibition on COMADEM was launched in 1988 in Birmingham at the Birmingham Polytechnic (now called the University of Central England). This was then followed by organizing annual COMADEM International congresses and exhibitions at a number of prestigious UK universities and higher educational institution including Brunel University (1990), Southampton Institute (1991), University of West of England (1993), University of Sheffield (1996), University of Sunderland (1999), University of Manchester (2001), University of Birmingham (2002), Robinson college, Cambridge (2004) and Cranfield University (2005). The Congress and Exhibitions was hosted by well-known research/professional and academic establishments such as, Centre Technique des Industries Mecaniques (CETIM) in France (1992), Steel Authorities of India Ltd & IIT Delhi in India (1994), Queen's University in Canada (1995), Technical Research Centre of Finland (VIT) (1997), Monash University in Australia (1998), The Society for Machinery Failure Prevention Technology (MFPT) in USA (2000), Vaxjo University in Sweden (2003), Lulea University of Technology in Sweden

(2006) and University of Coimbra in Portugal (2007). Through this international networking, researchers from industries and academia have effectively promoted knowledge discovery, generation and dissemination processes on various topical themes. This quest will continue unabated. COMADEM International Congress Proceedings, which are standard source of references have been published by reputable publishing companies and are distributed worldwide.

(C) International Journal of COMADEM

The multidisciplinary-based International Journal of COMADEM was successfully launched in 1998. The journal is totally dedicated to encourage, nurture and promote topical areas such as, Innovation & Entrepreneurship, Sensor Technology, Education & Training, Signal Processing, Intelligent Manufacturing, Data Communication & Management, Machinery & Process Health Monitoring, Health & Safety, Failure Prediction & Diagnosis, TQM, Asset Management, RCM, TPM, Energy & Environmental Management, IST, Risk Management, Technology Management, Bio-Medical Engineering, Logistics, Structural Health Monitoring, Industrial Metrology, Industrial Tribology, Industrial Machine Vision, Knowledge Engineering & Management and Human Factors in Engineering. This is a multidisciplinary-based refereed journal with a strong membership on the International Editorial Board of distinguished experts drawn from academic, professional and industrial backgrounds. The journal focuses on all aspects of intelligently and proactively monitoring the key performance/health indicators of a wide variety of industrial assets. The journal's mission is to publish the latest information speedily and accurately in order to aid decision makers in industry, R & D organizations, academic/professional establishments, government agencies, maintenance personnel, educationalists and students alike. To the best of our knowledge, there are no refereed multidisciplinary-based learned journals, which would authoritatively cover the proactive management of industrial assets.

(D) Collaborative Research & Development COMADEM Activities

COMADEM International has been actively engaged in many collaborative industry-academy funded research & development activities. The countries involved included India, Korea, PRC, Jordan & Bahrain. This is categorized under the following headings:

- Bearings Health Monitoring.
- Machine Tool Wear Monitoring.
- Compressors Performance Monitoring.
- Turbo-generator Health Monitoring.
- Robotics Control.
- Electrical Insulation Monitoring.
- Knowledge-based Logical Reasoning.
- Flexible Manufacturing Systems Health Monitoring.
- Gears Health Monitoring.
- Mining Machinery Health Monitoring.
- Maintenance Engineering & Management.

➢ Advances in Sensor Technology.

➢ Structural Health Monitoring.

A number of novel and innovative approaches were developed. These included the following:

1. On-Line Monitoring & Adaptive Control of bearing performance under running-in conditions.

2. Application of Artificial Intelligence Techniques such as ANNs (MLP with Error Back-Propagation Learning, RBF Neural Networks, Resource Allocation Networks, Growing Cell Structures Networks, Fuzzy-based Reasoning (Feature-Filtered Fuzzy Clustering, Fuzzy Nearness Degree, Fuzzy clustering and Fuzzy Comprehensive Judgment), Genetic Algorithms, Walsh Spectral Analysis, Wavelet-based Bispectrum Analysis, Generative Topographic Mapping, Finite Element Modelling Technique for gears, compressors, turbogenerators, machine tools, FMS, robotic manipulators, machining centres.

3. Application of Chaos & Fractal Theory to Mechanical Cracks and Partial Discharges in Electrical Insulation.

4. Theoretical development of Temporal First Order Nonmonotonic Logic (TFONL), Multi-agent Diagnosis, Extended TFONL, Diagnostic Temporal Reasoning in Model-based Diagnosis for modern complex systems.

5. Development of COMO maintenance software for monitoring Machine Tool Performance, Development of Data Archiving Software using OraclePro - C, Maintenance Audit System for Oil & Gas Industry & Thermal Deformation Model for a Machining Centre.

6. Experimental Modal Analysis for Robotic Manipulators, Hybrid Finite Element Analysis and Hybrid Genetic Algorithms for Structural Health Monitoring of Aircraft Structures.

(E) Participation in ISO activities to develop Standards on Condition Monitoring and Diagnostics of Machines

The author was nominated by the BSI Sub-Committee GME/21/7 on Condition Monitoring to actively participate in ISO/TC 108/SC 5 meetings to develop ISO Standards on various aspects of Condition Monitoring and Diagnostics of Machines. Considerable progress has been made to publish relevant standards in this multidiscipline.

The Current Global Issues Facing Industrial Sectors

Some of the current key issues facing the industrial and economic sectors are briefly stated in the following:

➢ Accelerated revolutionary trends in the scientific, technological, engineering and management fields.

➢ Accelerated and ambitious global trends in the industrial competitiveness.

➢ Increasing trend in the global investment in science, technology and innovation fields.

➢ Increasing concern on the growing ethical issues facing the Society of the scientific and technological advances.

➢ Growing trends in frauds, security lapses and terrorism.

➢ Increasing concern over the accelerated depletion of natural resources.

➢ Increasing concern over the global pollution (wastage disposal of radio active materials, Carbon

dioxide and other obnoxious gas emissions, electromagnetic interferences, high voltage radiation, etc.).

- Increasing trends in Systems Complexity.
- Increasing trends in the number of Systems Failures and its undesirable consequences.
- Inadequate supply of knowledgeable human resource to proactively manage the industrial assets.
- Inadequate availability of industrial best practices/benchmarking studies.
- Poor awareness and appreciation of available international/national Standards.
- Poor supply of multidisciplinary-based experts.
- Lack of intelligent databases.
- Lack of Key Performance Indicators (KPIs)
- Lack of open public dialogue/debate on major global issues (including cultural/spiritual issues). Cultural barriers impede progress.

Some of these aspects will be further discussed in the following:

On Failure Scenarios

There are many 'depressing news' reported in newspapers, TV, and radio media about many failures encountered in engineering systems, manufacturing systems, process systems, business systems, medical systems, educational systems, legal systems, political systems, socio-economic systems, defence systems. Failures occur due to natural causes/human induced/interaction between the two. The eternal cyclical natural processes of creation, maintenance and destruction on different time scales is the Universal Law of Nature, which extends from nano to macro scales. Failure causes destruction. The Universal Law of Failure appears to encompass all human endeavours and beyond. Failure (F) is a function of the all-embracing attributes of individual (A), degree of intelligent knowledge the individual possess (I) and the ability to logically reason and analyse all the facts (L). Hence the famous time-honoured adages 'what goes up must come down', 'To err is human', etc. Understanding failures helps in forecasting/minimising failures, which extends the useful life of the assets. Generally, failures are found to be multicausal, arising from complicated, interactive and interdependent activities. Engineering is still not an exact science. Lack of precise knowledge (and other constraints) often forces the designer/manufacturer/decision maker to rely upon judgement, intuition, and above all, sound experience. Many successful designs are based upon experience with earlier designs, which have proved reliable, economic and efficient. Today's customers, however, continually demand novel goods/services with superior performance, higher efficiency and lower costs. This, therefore, puts a constant pressure on the designer/manufacturer to go beyond the limits of proved experience. Serious failures are not due to 'silly mistakes' but to stepping beyond the limits of available knowledge and experience. In some cases (especially in the fields of Astronautics/Nanosciences/Nanotechnology (Nanoelectronics) /Nanobiotechnology) we are encountering unknown types of failure modes, which has never been expected/experienced before! Managing failures is a skilful, challenging and daunting task. Failures can be sometimes beneficial. As we know, sometimes failure is the mother of invention!