Mechanism and Machine Theory 000 (2017) 1–28

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Creativity in design–Science to engineering model

J.S. Rao

Chief Editor Journal of Vibration Engineering and Technologies, Chief Science Officer (Consulting) Altair Engineering, Bangalore, India

ARTICLE INFO

Article history:
Received 25 July 2017
Accepted 29 August 2017
Available online xxx

Keywords:
Design
Creativity
Science to engineering
Fusion reactor
Liquid Lithium Ceramic Breeder

ABSTRACT

This paper is written in honor of my long term friend and mentor Professor Bernard Roth who spent over six decades in Academic contributions devoted to Kinematics, Dynamics, Control, and design of computer controlled mechanical devices. He is continuing actively in his work from the famous school Hasso Plattner Institute of Design cofounded at Stanford (popularly known as d.school). As an Academic Director he is active in Creativity in Design. This paper explores the idea of Creativity directly from Science of 17th–18th centuries in place of Engineering evolved by Professor Timoshenko at Stanford in early 20th century at the time of rapid expansion of rotating machinery from de Laval in 1882. An example of design that involves extreme temperature ranges, magneto hydrodynamics and optimization in a fusion reactor to produce tritium fuel will be described.

1. Introduction

Engineering is defined as “The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property.”, see Cooperrider [3]. Design definition begins with *creative application of scientific principles*.

The Paleolithic, or Old Stone Age, was the longest that began about 2 million years ago, when stone tools were first used by humanoid creatures, and ended with the close of the last ice age about 13,000 BCE, see Rao [14]. Around that time man found that a section of the tree trunk was able to move under the force of gravity because it was round. If the branches and twigs of the trunk were removed, the speed of the rolling log improved, see Fig. 1. This is probably the beginning of creativity in Design. Rao [14] also talked about Hero’s steam turbine, water turbines and wind turbines amongst others much before science revolution. The scientific thought led to atmospheric or vacuum engines and James Watt made the first real application of Black’s latent heat discovery to usher the industrial revolution, see Ogg [11]. The work of James Watt, see Rao [12] is thus the application of science to engineering which led to the birth of industrial revolution.

Science Revolution began in 17th century and defined Science of Solids, Fluids, Electromagnetism …, but was too complex in pre-digital era involving several coupled partial differential equations of the state variables. The reciprocating steam engine of 18th century ushered the industrial revolution but did not warrant any design principles as we know in 20th century. It is the first practical rotating machine of de Laval and the dynamo of Alva Edison in 1882 that changed the face of the world, see General Electric [6] and Rao [14]. This also required a major revision in the way in which *design* is taught in our engineering schools.

E-mail address: tvii2k@yahoo.com

http://dx.doi.org/10.1016/j.mechmachtheory.2017.08.023
0094-114X/

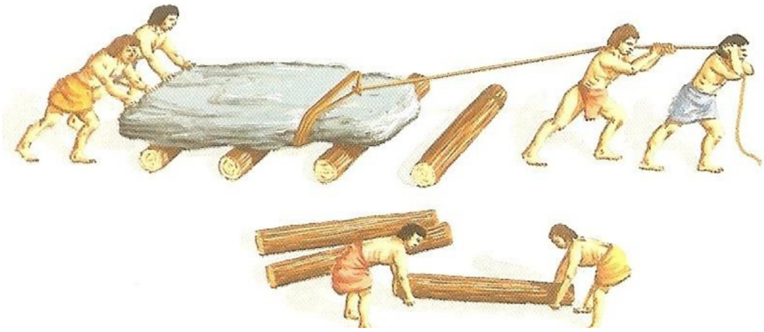

Fig. 1. Man's earliest *creativity* achieved to pull and push under log rollers.

Professor Stephen Timoshenko wrote the first version of his famous Strength of materials textbook during 1907 to 1911 at Kyiv Polytechnic Institute in Ukraine. He moved to US in 1922 and joined Westinghouse, an exciting place to be during the 1920s. This was a period of industrial growth and expansion providing challenges in Mechanics where Timoshenko became the most influential person. The five years that Timoshenko spent at Westinghouse have been called its "Golden Era of Mechanics". His book on Strength of Materials was written in English in two volumes and published in 1930. Subsequently he abridged these two volumes into one and published Elements of Strength of Materials primarily addressing undergraduate students in American colleges in 1935. Since then many books appeared in this subject matter.

From Westinghouse Electric Corporation in 1927, he became a faculty professor in the University of Michigan where he created the first bachelor's and doctoral programs in engineering mechanics. From 1936 onward he was a professor at Stanford University. He was the leading point to transform engineering education around the world by bringing *Approximate Engineering Approach in Design*. This enabled advanced design in all fields of engineering activity. Different disciplines in engineering were borne from Science. They are actually domains in applications of Mechanical, Electrical, Aeronautical, Marine etc. besides Static Structural engineering of Civil Engineering. However, they all emanated from just Science of 17th and 18th centuries.

In absence of computational means, Timoshenko's approach became widespread throughout the world; the basic equations of scientific revolution got simplified. Navier-Cauchy equations are given in 1822 involving 15 state variables, a set of coupled partial differential equations, see Rao [19]. Similar is the case with Euler equations given first in 1755 and Navier–Stokes equations involving viscous effects; they are seven coupled partial differential equations with seven state variables, see Rao [20]. Therefore the need for approximations and Professor Timoshenko pioneered in this engineering effort. Factors of safety, Stress concentrations, testing during design all became norm of the day. Until the end of 20th century these time consuming and expensive methods prevailed in academia as well as industry. Things began to change in this approach ever since digital computers became affordable and common.

The invention of digital computer using valves in Philadelphia (ENIAC) during the II World War has changed the scenario gradually; this was accelerated by Transistors and subsequently Integrated Circuits in 1960's and it is all on a sudden a boom for number crunching. The high performance computing that followed gradually replaced engineering approximations through Strength of Materials by Elasticity and Lagrangian approach.

Initially the computers are main frames, each research institute having one central facility with punching machines for cards for input to the computer, e.g., IBM 360. Research laboratories wrote out computer programs in Fortran and Algol languages. The output from the computer was also in the form of cards and printouts from these cards were taken and processed by hand to understand the results. Even the expensive supercomputers of late 1980's are small in memory and speed when compared with computer clusters today. The industry was also following this cumbersome and expensive procedure. Academic institutions by necessity had individual researchers having programs exclusively with them.

Things have changed with high performance computing. It is now "Science to Engineering" or "Simulation Based Engineering Science SBES" through several commercially available codes to do the drudgery arising out of Finite Element Methods or Finite Volume Methods. This has revolutionized the outlook for designs; what used to be months of design time by several skilled engineers, it is now few seconds of numerical effort.

2. Stanford and other initiatives

With changing times Stanford University Mechanical Engineering adopted curriculum that expects Undergraduates to demonstrate the following amongst other things through their projects:

- Application of knowledge of mathematics, science, and engineering.
- Design and conduct experiments, as well as to analyze and interpret data.
- Design a system, component, or process to meet desired needs.
- Ability to function on multidisciplinary teams.

Please cite this article as: J.S. Rao, Creativity in design–Science to engineering model, Mechanism and Machine Theory (2017), http://dx.doi.org/10.1016/j.mechmachtheory.2017.08.023