

Unification of newtonian mechanics and thermodynamics

Introduction

It is my pleasure to write this article for the inaugural issue of the Online Journal of Civil Engineering (MOJCE). I would like take this opportunity to report on important recent advances in mechanics, which is the primary basis for all civil engineering fields. Classical Newtonian mechanics is based on the work of Isaac Newton “The Principia was published on 5 July 1687 with encouragement and financial help from Edmond Halley. In this work, Newton stated the three universal laws of motion. Together, these laws describe the relationship between any object, the forces acting upon it and the resulting motion, laying the foundation for classical mechanics.¹ The equation “ $F=ma$ ” is the basis of Newtonian mechanics. Based on Newtonian mechanics, all subsequent theories in mechanics were developed, such as the Theory of Elasticity, the Theory of Plasticity and others. However, the Newtonian mechanics does not account for past, present, or future of the system. If we have a single degree of freedom spring we can calculate the deflection in the spring. However, the parameters of the spring and the load change every day. If we measure the deflection of the spring the first day put in service, probably we will get the deflection value predicted by Newtonian mechanics. However, if we measure the deflection of the spring near the end of its fatigue life it will be much larger and finally the spring will fatigue and break in two Pieces. Contrary to popular opinion fatigue happens under all stress levels, according to thermodynamics there is no fatigue limit, best example is the fatigue failure of the pendulum at Big Ben clock in London. This change in the system response deflection in the spring example actually does not happen overnight it happens every day according to laws of thermodynamics. Hence, Newtonian mechanics assumes systems don’t change. On the other hand the field of thermodynamics governs past present and future of the systems. Around 1850 Rudolf Clausius and William Thomson Kelvin stated both the First Law and the Second Law of Thermodynamics.²

In the last 150 years there were many attempts to unify Newtonian mechanics and thermodynamics. Most were either based on phenomenological models and had no physical basis or they were system specific, loading type specific and case specific. One example is the damage mechanics theory proposed by L. M. Kachanov in 1958 and later improved by J. Lemaitre, J. L. Chaboche, G. Voyiadjis and others. Their approach has been mainly phenomenological in essence. Material needs to be tested to failure to obtain material properties and then to create a damage potential surface for each loading type (mechanical or electrical or radiation) the same way a yield surface is created. Then this surface is used to integrate future degradation of the system into Newtonian mechanics equations. In 1997 Cemal Basaran proposed a thermodynamics theory of solids to unify Newtonian mechanics and thermodynamics. According to this theory, displacement (or force) alone cannot be an unknown of the equilibrium equation as stated by Newtonian mechanics. This unified theory used, displacement or force, entropy and entropy generation rate as nodal unknowns of any system. In the unified theory any system always travels between 0 state and 1 state. Zero can be considered virgin state

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and 1 damaged state or the last stage in that form. For example, a new bridge or a new born baby will be in 0 state and when the bridge or the person collapse or die they are at 1 state. Some people can live to be 100 years old and some people die at 70 or someone can have a car accident and die at 20. Their age with respect to time is different. But what unifies them is their final state, which is 1. This progress between 0 and 1 can be calculated without the need for any phenomenological curve fitting damage potential surfaces, or any other curve fitting constitutive models. In the thermodynamic theory of solids, every point in space has 3 variables, displacement or force, entropy and entropy generation rate. Of course the strongest feature of this theory is that it is universal. All load types can act on the system at the same time, while all will not create a displacement response in Newtonian mechanics, like an electrical load or chemical corrosion, but they will all create irreversible entropy generation, which is additive. Of course non-linear interaction between mechanisms must be taken into account. This theory was experimentally verified extensively by Cemal Basaran group in Buffalo, NY and other researchers around the world, including but not limited to Prof. Michael Khonsari of Louisiana State University, Prof. Mohammed Modarres of University of Maryland at College Park, and many others. Mechanical, thermal, electrical, chemical and radiation loads were used to prove this unified theory by experiments. However this unified thermodynamics theory of solid mechanics lacked a mathematical proof. In 2016 Prof. Leonid Sosnovskiy and Prof. Sergei Sherbakov of Belarusian State University came up with this mathematical proof.³ In the paper, they state that “Mechanics from its side and thermodynamics from its side consider evolution of complex systems, including the Universe. Classical thermodynamic theory of evolution has one important drawback since it predicts an inevitable heat death of the Universe which is unlikely to take place according to the modern perceptions. The attempts to create a generalized theory of evolution in mechanics were unsuccessful since mechanical equations do not discriminate between past, present and future. It is natural that the union of mechanics and thermodynamics was difficult to realize since they are based on different methodologies. We make an attempt to propose a generalized theory of evolution which is based on the concept of tribo-fatigue entropy. Essence of the proposed approach is that tribo-fatigue entropy is determined by the processes of damageability conditioned by thermodynamic and mechanical effects causing to the change of states of any systems. Profs Sosnovskiy and Sherbakov suggested

naming the theory Mechanothermodynamic for short. They suggested the following 3 laws.

Laws of mechanothermodynamic

- A. Damage is a fundamental intrinsic physical property (and the functional duty) of any system and all of its elements.
- B. Damage of each object any existing one inevitably grows up to its breakdown-decomposition (disintegration) into a set of particles of arbitrarily small size, i.e., it is the unidirectional process of time.
- C. Not only the unity and struggle of opposites damage and healing but also the directivity of various and complex physical processes, such as hardening-softening-healing, are typical of the evolution of a system.

A short detailed summary of the unified theory can be given as follows from a paper on the topic.⁴ The entropy production is a non-negative quantity based on irreversible thermodynamics and thus serves as a basis for the systematic description of the irreversible processes occurring in a solid system. A thermodynamic framework can be formulated for Newtonian mechanics of solid materials, where the equations can account for past, present and future of the system. Entropy production and its rate are used as the sole measures of evolution in the system. As a result, there is no need for physically meaningless empirical parameters to define phenomenological damage potential surface or test data curve fitted Coffin-Manson, or Wei bull functions to “predict” degradation evolution. The unified theory is founded on the basic premise that a system obeys the first and the second laws of thermodynamics. Entropy in a system changes for two reasons. First, because entropy flows into the volume element. Second, it changes because there is an entropy source due to irreversible phenomena inside the volume element. The entropy source is always a non-negative quantity, since entropy can only be created, never destroyed and when the entropy generation rate goes

to zero system fails, reaches 1 state. For reversible processes the entropy source vanishes. To relate the entropy source explicitly to the various irreversible processes that occur in a solid system, one needs the macroscopic conservation laws of mass, momentum and energy in local, i.e. differential form. These conservation laws contain a number of quantities such as the diffusion flow, the heat flow, the stress tensor, and the electromagnetic tensor which are related to the transport of mass, energy and momentum. The entropy source may then be calculated by using the thermodynamics Gibbs relation. The entropy source strength can thus serve as a basis for the systematic description of the irreversible processes occurring in a solid system. Yet the entropy balance equation and laws of conservation cannot alone be used to solve the initial and boundary value problem, since this set of equations contain the irreversible flux as unknown parameter. These equations must be tied to the system specific in this case solid continuum Newtonian mechanics relationships to be meaningful and facilitate the solution of initial and/or boundary value problems.

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Conflict of interest

The author declares no conflict of interest.

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