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AN INTEGRATED APPROACH FOR THE ENGINEERING DYNAMICS COURSE

S. R. Ibrahim

Professor of Mechanical Engineering
Old Dominion University
Norfolk, Virginia, U.S.A

ABSTRACT

This paper aims at studying the feasibility of a new approach for teaching the dynamics course, which is usually taught in the sophomore year of engineering curriculum. The new proposed approach is an integrated one, which will be designed to offer the general concept from which the special cases are easily addressed. The concept of rigid body dynamics will be first introduced as the general theory. Particle dynamics is then shown to be a special case of rigid body dynamics.

The suggested approach should be more direct, eliminates needless duplication and compartmentalization, avoids confusion and the perceptions of nonexistent differences and ultimately makes for effective learning and better understanding of the subject.

The contents of the dynamics course will be redesigned into a prototype to include four main sections, or chapters:

a) Kinematics,
b) Kinetics - Force and Acceleration,
c) Kinetics - Work and Energy,
d) Kinetics – Impulse and Momentum.

This is compared to the current methods that include eight sections, four for particles and then four for rigid bodies.

Theory derivations and application problems are to be revised to fit the new general and integrated approach.

The proposed concept is expected to save valuable time, which will be utilized to introduce more applications and practice on rigid body dynamics.

In addition, the new approach is expected to enhance the understanding of the dynamics principles, which are essential throughout the engineering education as well as practice. The integration of topics will allow students to learn related concepts simultaneously. This promotes a broader based level of understanding as compared to the current more narrow application-specific understanding of each topic. The resulting knowledge will go far beyond improving a sophomore-engineering course in the sense that such knowledge is essential in product design and safety.

1. INTRODUCTION AND JUSTIFICATION

Dynamics, which is the second course in engineering mechanics after statics, is a fundamental course in most fields of engineering studies as well as physics and mathematics. While dynamic equilibrium is a natural extension of static equilibrium, students usually have more difficulties understanding the concepts of motion, effective forces and inertia when applied to particles and rigid bodies. Especially puzzling and confusing to students is the division of the same concepts when they are applied to a particle or to a rigid body.

Most of the existing dynamics textbooks, which are used by majority of engineering educational institutions in the U.S., have practically the same organization. For example, in a typical and popular textbook, [1], the first eight chapters are entitled as follows:

i. Kinematics of a Particle,
ii. Kinetics of a Particle: Force and Acceleration,
iii. Kinetics of a Particle: Work and Energy,
iv. Kinetics of a Particle: Impulse and Momentum,
v. Planar Kinematics of a Rigid Body,
vi. Planar Kinetics of a Rigid Body: Force and acceleration,
vii. Planar Kinetics of a Rigid body: Work and Energy,
viii. Planar Kinetics of a Rigid Body: Impulse and Momentum.

It can be seen from the list above that the second four chapters on rigid bodies parallel and repeat the first four chapters on particles. In a typical fifteen weeks semester, the second half of the course is rushed through and justly so since it addresses the same concepts detailed in the first half. This results in deficient knowledge and practice of rigid body dynamics. In most cases students miss the fact that the particles in the first four chapters are in fact rigid bodies that do not rotate. As well, the fact that most of the equations in the second half of the course are applicable to particles if the mass moment of inertia and or rotation are set to zero. Also missed in the present arrangement is the fact that rigid body kinematics parallel exactly the equations of kinematics of a particle in cylindrical coordinates with the length between two points being a constant.

In a second dynamics textbook, [2], the chapters are as follows:

i. Introduction,
ii. Motion of a Point,
iii. Force, Mass and Acceleration,
iv. Energy Methods,

v. Momentum Methods,
vi. Planar Kinematics of Rigid Bodies,
vii. Planar Dynamics of Rigid Bodies,
viii. Energy and Momentum in Rigid body dynamics.

A third book table of contents, [3], lists its chapters as:

i. Introduction to Dynamics, Kinematics of Particles,
ii. Kinetics of Particles,
iii. Work and Energy Principles for Particles,
iv. Momentum Principles for Particles,
v. Kinematics of Rigid Bodies,
vi. Plane Kinetics of Rigid Bodies,
vii. Energy and Momentum Principles and Plane Motion of Rigid Bodies.

The above-mentioned three textbooks cases establish the consistency of the current organization of topics. This is based on deriving equations for a single particle then extending the derivations to a system of particles and in the second half of the course applying the system of particle equations to rigid bodies.

To further elaborate on the repetitious and confusing nature of the existing dynamics course, a brief discussion on equations is included here. In [1], the following equations, with their original numbering, make the point:

$$\boldsymbol{v} = \dot{r}\,\boldsymbol{u}_r + r\dot{\theta}\,u_\theta \qquad (12\text{-}24)^*$$

$$\boldsymbol{a} = \left(\ddot{r} - r\dot{\theta}^2\right)\boldsymbol{u}_r + \left(r\ddot{\theta} + 2\dot{r}\dot{\theta}\right)\boldsymbol{u}_\theta \qquad (12\text{-}28)$$

$$\boldsymbol{v} = \boldsymbol{\omega} \times r \qquad (16\text{-}9)$$

$$\boldsymbol{a} = \boldsymbol{\alpha} \times \boldsymbol{r} - \omega^2 \boldsymbol{r} \qquad (16\text{-}14)$$

In equations (12-24) and (12-28) from Chapter 12 on ‘Kinematics of a Particle’, if the quantity (r) is set to a constant, this result in equations (16-9) and (16-14) from Chapter 16 on ‘Planar Kinematics of a Rigid Body’. The separation between chapters 12 and 16 results in that the students become unable to relate $\dot{\theta}$ to ω and $\ddot{\theta}$ to α and in turn miss having a good understanding of the general concepts. In addition, they become accustomed to treating the special applications of the same concept as separate and independent situations.

Additional examples on the repetitious and confusing current organization are the following equations, with their original numbering, from [1]:

$$\sum \boldsymbol{F} = m\boldsymbol{a} \qquad (13\text{-}4)$$

* Equations are not numbered sequentially but have same numbers as in the reference textbook.

$$\sum \boldsymbol{F} = m\boldsymbol{a}_G \qquad (17\text{-}10)^{*}$$

$$\sum M_G = I_G\alpha \qquad (17\text{-}11)$$

$$T_1 + \sum U_{1-2} = T_2 \qquad (14\text{-}7)$$

$$T_1 + \sum U_{1-2} = T_2 \qquad (18\text{-}13)$$

$$T_1 + V_1 = T_2 + V_2 \qquad (14\text{-}21)$$

$$T_1 + V_1 = T_2 + V_2 \qquad (18\text{-}18)$$

Here equations (13-4), (14-7) and (14-21) are repeated as equations (17-10), (18-13) and (18-18) respectively. The fact is that the only difference between the equations of chapter 14 and those of chapter 18 is the rotational kinetic energy. Equations (13-4) and (17-10) are identical in every aspect. Furthermore, even equation (17-11) for rigid bodies is in fact applicable to the particles in chapter 13 since for a particle either the inertia and or the rotation are equal to zero.

1.1 The Time Factor

A typical dynamics course is a one-semester course. This means about fourteen weeks to cover eight chapters. However, this time is never divided equally or near equally between the first and second halves of the course. Usually, the first four chapters, on particles, consume the larger portion of the semester time. This leaves insufficient time to cover the remaining four chapters on rigid bodies. Most of that time is devoted to the kinematics part, leaving too little time to address the kinetics part.

Integrating particles and rigid body dynamics would allow for the more needed practice on rigid body dynamics. The numerous examples addressed in class on particle applications, can and should be on rigid bodies in an integrated course. After all, covering and understanding rigid bodies cover and explain particles by default.

2. MERITS OF INTEGRATION

Integration of curriculum in engineering has been extensively discussed in the literature, [4-11]. Such integration however is across courses and none was found which addresses integration within one particular course. The publications on the subject detail the disadvantages of the compartmentalization of different courses. Such argument would naturally and logically apply to the even more serious and unnecessary compartmentalization within one course.

A study, which began in 1993, for the National Science Foundation was conducted by a consortium of universities known as Foundation Coalition has extensively supported the concept of courses' integration. The Coalition included Arizona State University, Maricopa Community

[*] Equations are not numbered sequentially but have same numbers as in the reference textbook.

College, Rose-Hulman Institute of Technology, Texas A&M Kingsville, Texas A&M University, Texas Woman's University and the University of Alabama. One main recommendation by the coalition, out of four recommendations to achieve major improvements of undergraduate engineering education, was the integration of science and mathematics into problem solving and design, [5]. Texas A&M, [6-8] experimented with integrating science courses, such as physics, with calculus and showed the concept to be meritorious, [7-8]. Another study, also supported by NSF, was carried out by Drexel, [9]. The purpose of that study was to cultivate in an integrated fashion the common mathematical and scientific foundation in the freshman year of Drexel's E4 program. The integration was achieved through the courses Mathematical and Scientific Foundation of Engineering I, II, and III, which addressed combined calculus, chemistry, and physics.

In [10] integration went beyond the freshman engineering to cover the entire engineering curriculum. This study supported the concept that integration help engineering students to better "understand the functional core of the engineering process."

Another extensive evaluation of First-Year Integrated Curricula, [11] listed ten advantages and five disadvantages to the approach. Fortunate for this proposed approach, the disadvantages dealt with the logistics of managing different courses and different instructors. The advantages, each and every one of them, strongly highlight the national need for this proposed project. Most important is the one advantage in the subject paper stating: "Re-arranging topics so students learn related concepts simultaneously promotes a broader based level of understanding rather than a more narrow discipline-specific understanding of each topic" – the very same objective of this proposed project.

3. PROPOSED APPROACH

The idea behind this suggested approach is to introduce an integrated method to present the fundamental concepts of dynamics. Theories are to be derived in a manner that does not differentiate between a particle and a rigid body. The contents of the proposed course will be divided into four main sections:

i. Kinematics,

ii. Newton's Second Law: Force and Acceleration,

iii. Newton's Second Law: Work and Energy Methods,

iv. Newton's Second Law: Impulse and Momentum Methods.

Such an approach is not merely a reorganization or combination of the existing course's eight sections. It is totally a new approach that requires a new construction of principles as well as derivations and application problems. Offering the general integrated concepts of dynamics will allow for better understanding of such concepts.

Rigid body kinematics need to be incorporated in the first chapter on kinematics. The section on cylindrical coordinates is the perfect place for addressing rigid body kinematics. Indeed, if radial distance "r" in plane cylindrical coordinates is constant, the very equations for a particle render themselves applicable to velocity and acceleration analysis of two points on a rigid body.

It may also be advantageous to delete the concept of rectilinear motion and introduce position, at the very beginning, as a vector comprising a scalar quantity and a unit vector. Velocities and acceleration are then derived from differentiating the scalar quantity and the unit vector. If motion is on a straight line, it follows by having zero for unit vector derivatives. Differential relations of scalar quantities, in this way extend naturally to angular rotation.

In the kinetics sections, all derivations are to be for rigid bodies. If there is no rotation, or the object has no dimensions, the special situation of a particle is readily available. No engineering student should be taught that the kinetic energy is $\frac{1}{2}\ mv^2$ because later on they forget that this is for a particle only. It is more sensible as well as logical to be taught that in plane motion the kinetic energy is $\frac{1}{2}\ mv^2 + \frac{1}{2}\ I_G\omega^2$. Again, if $I_G = 0$ or $\omega = 0$, the particle case is satisfied.

4. CONCLUSIONS

An integrated approach for teaching the engineering dynamics course has been sketched and justified. The proposed approach is aimed at deriving the dynamics principles for rigid bodies from the start. The special case of particles naturally follows from the general formulae. The new approach may improve the teaching of dynamics by eliminating confusion and repetition.

NOTE:

This paper is merely a proposal to reorganize the contents of the dynamics course and it by no means intended directly or indirectly to critique the dynamics textbooks used here as references.

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6. BIOGRAPHICAL INFORMATION

DR. SAM R. IBRAHIM is currently a Professor of Mechanical Engineering at Old Dominion University in Norfolk, Virginia, USA. Dr. Ibrahim’s research contributions in Modal Analysis are numerous and include the Ibrahim Time Domain (ITD) Modal Identification Technique. Ibrahim has been teaching engineering mechanics, machine design, mechanisms, vibrations and modal analysis for forty years.