International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 12 (2017) pp. 3177-3181

Reviews on Five Subjects in Mechanical Engineering that Need Rehabilitations in Presentation

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Abstract

We found several important subjects that should be taught to the newcomers clearly and may be to some scholars too. Without these cleared subjects, people of now and future concerned with mechanical engineering may not be free from a certain chaos or unclear understanding. The term stress has many similar meanings to be identified; stress vector, stress tensor, and component of stress. Mohr's circles adopt four different sign conventions that need a comprehensive understanding. Choice may be mathematical or engineering sign of shear stress, and plus or minus sign of shear stress mapped to Mohr's circle. Third and fourth items are minor, however, need a correction and to be presented in an old best figure. The final and important item is unit system. A subsystem of SI, mm-Mg-s-N system, is proposed which don't need any consideration or conversion of units by error-prone individuals.

Keywords: Stress, Mohr's circle, Contact stress, Bolted joint, Sub-SI system.

INTRODUCTION

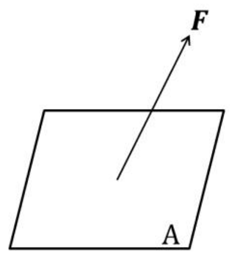
Mechanical engineering has long been devoted to enabling mankind, and will continue to do so forever. It may be divided into the following categories: mechanics, thermodynamics, heat transfer, mechanical design, manufacturing, automatic control, materials, (as of recently) biomechanics, nanophenomena, etc. Although, some subjects are studied and taught at length, the methods for presenting them remain narrow-sighted, inefficient, and often incorrect. These improper presentation methods mislead even mature engineers and cause significant difficulty to new comers. Therefore, clear and comprehensive treatments of these subjects are necessary, which will ultimately aid the progress of mechanical engineering.

The five subjects [1-4] that will be discussed and provided with a proper means of presentation are as follows.

1. Comprehensive definitions of the renowned term 'stress'.
2. Comprehensive sign conventions of the four types of Mohr's circles.
3. Misuse of the formula for contact stresses in involute gears.
4. Use of an inefficient diagram for the fastened bolted joint under an external load.
5. The subsystem of the SI unit system for mechanical engineers.

COMPREHENSIVE DEFINITIONS OF 'STRESS'

According to most texts [1], stress is defined as 'the force per unit area'. It is wrong if it means stress tensor. However, there are technically three types of stress—the stress vector, the stress tensor, and normal and shear components of stress - that are explained as follows.



$$\boldsymbol{\sigma} = \frac{\boldsymbol{F}}{A}$$

Figure 1. Stress vector

The stress vector, $\boldsymbol{\sigma}=\boldsymbol{F}/A$, represents the force per unit area having three components with respect to the axes of Cartesian coordinate. This concept can be shown in Figure 1, where the force is assumed to be applied uniformly, or it should be differentiated.

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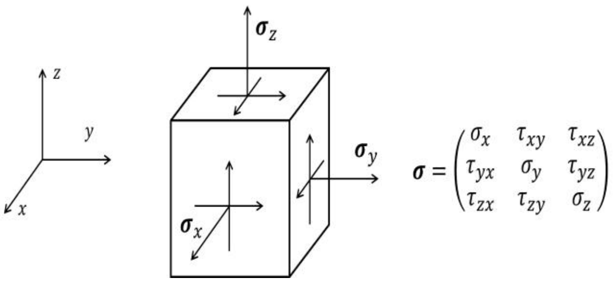

Figure 2. Stress tensor **σ**

The stress tensor is the concept expanded from the stress vector. We may represent a stress tensor in a form of matrix that combines stress vectors working on areas of three coordinate axes, as shown in Figure 2. It has 9 components that are symmetric; therefore it only has 6 independent components. When a force is applied to an inclined surface, the stress vector has 3 components in axial directions. In the meantime, it can be decomposed into 2 components, i.e. normal and shear components that are called normal stress and shear stress respectively as in Figure 3.

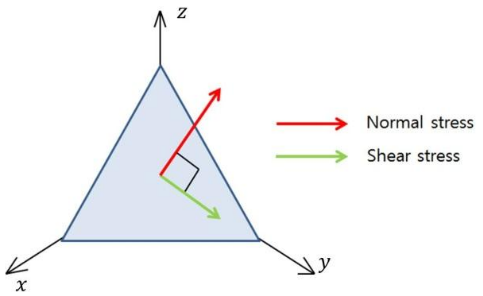

Figure 3. Normal stress and shear stress

Likewise the term stress serves for three concepts of mechanical quantities;

1. Stress (vector) : composed of three components on a surface
2. Stress (tensor) : composed of nine components (symmetric) at a point
3. (Normal or shear) Stress : represent component normal or shear on a surface

Comprehensive sign conventions of the four types of Mohr's circles

The Mohr's circle method differs amongst the versions of 'Mechanics of Materials' that are widely taught in universities, and is not properly explained. To facilitate the understanding of students who are studying mechanics of materials, we arrange four types of Mohr's circles in geometrical constructions according to the direction of the shear force acting on the elements and the rotating direction, as shown in Figure 4.

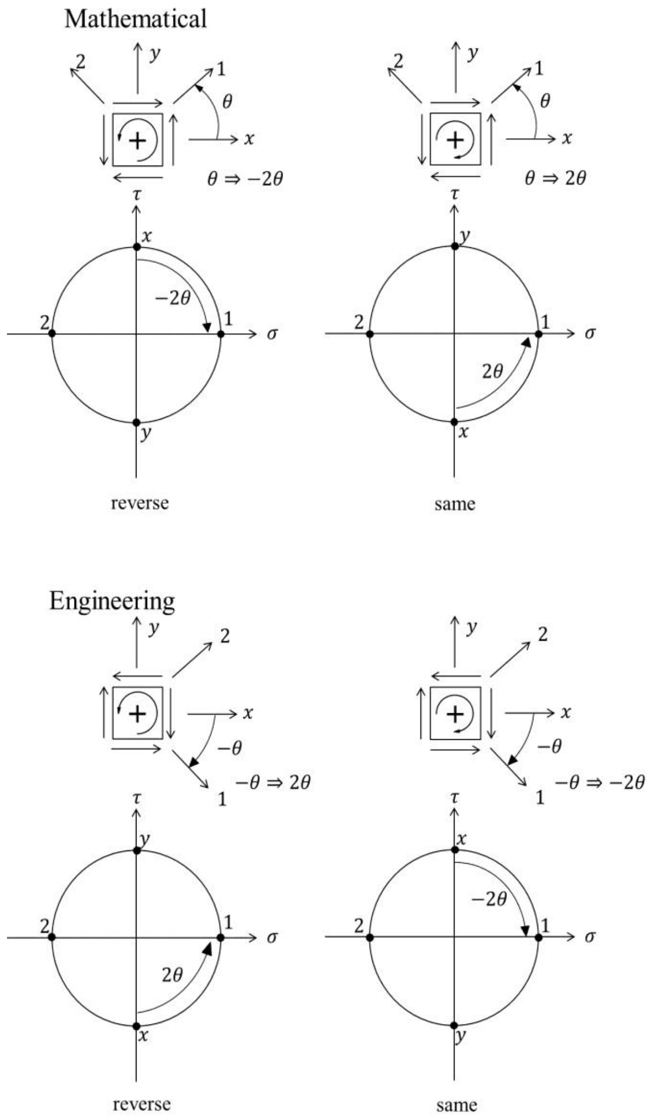

Figure 4. Types of Mohr's circles

There are four types of Mohr's circles depending upon the sign convention initially defined. Two ways of selecting positive shear force is available, mathematical and engineering. And another two ways of mapping actual angle θ to the angle 2θ in Mohr's circle by selecting counter clock wise (CCW) or clock wise (CW) as positive. For the mathematical and CCW convention, actual angle θ is mapped to the angle −2θ in Mohr's circle which can be confirmed by a sample example of pure shear case. Likewise the relation between other three cases rotational angles are given in the Figure 4. With this comprehensive understanding on the Mohr's circle, there will be no misunderstanding or confusion on the sign convention adopted by any text.

Misuse of the formula for the contact stresses of involute gears

Contact stress occurs when the gear and pinion engage each other at the surface. The contact-stress equation is Equation (1).

$$\sigma_c = C_p \sqrt{\frac{W_t}{FId} \frac{C_a C_m}{C_v} C_s C_f} \qquad (1)$$

Where each symbol has been defined by AGMA as given in many texts [2]. While many texts discuss contact stress, one of the variables of the formula, d is treated as the diameter of each mating gear, i.e. the diameter of gear for gear and that of pinion for pinion, respectively. However, the variable d should be the diameter of the pinion, i.e., d_p for both gear and pinion. Because of Newton's third law, the gear and pinion have the same contact stress when they engage each other.

Use of inefficient diagram for tightened bolt joint under external load

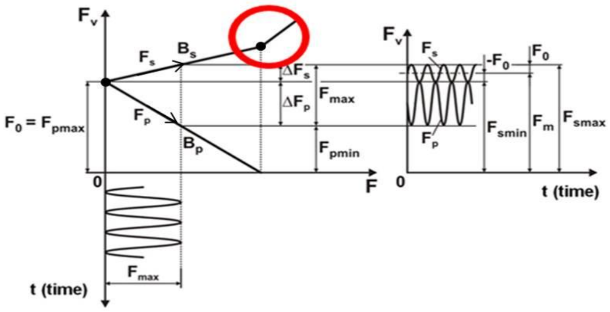

Figure 5. Load-load diagram

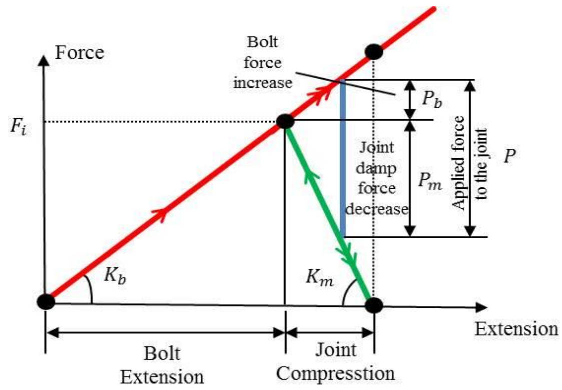

Figure 6. Load-extension diagram

Some texts [3] use rather complicated diagram (external force – part force diagram) similar to that shown in Figure 5, without mentioning that the gradient of line in red circle is 1. The external force-part force diagram doesn't give clear insight on the inter relation of the bolt load and member load. Moreover, the line has a sudden change of gradient after the critical point where the compression in the member becomes zero. As shown in Figure 6, the bolt load has no change in the gradient after the critical point in extension-part force diagram which explains the problem more strait forwardly and simple. In other words, Figure 6 explains the problem from the very initial state (black dot) to final state (black dot) through the critical state (black dot) through the arrow marks > and >>, however, Figure 5 starts from the fastened state neglecting the history of the tightening.

The following Equations (2) to (6) summarize the mathematical information where the subscript b for bolt and m for member, and F_i denotes the joint tightening force:

$$\boldsymbol{F_b = F_i + P_b} \qquad (2)$$

$$\boldsymbol{F_m = -F_i + P_m} \qquad (3)$$

$$\boldsymbol{P = P_b + P_m} \qquad (4)$$

$$\boldsymbol{F_b = F_i + \frac{k_b}{k_b + k_m} P} \qquad (5)$$

$$\boldsymbol{F_m = -F_i + \frac{k_m}{k_b + k_m} P} \qquad (6)$$

where

$\boldsymbol{F_b}$: bolt load

$\boldsymbol{F_m}$: member load

$\boldsymbol{P}$: external load shared by bolt and member

$\boldsymbol{k_b}$: bolt stiffness

k_m : member stiffness

Subsystem of SI units for mechanical engineers

SI units are widely used in the world; however, the SI unit of length (m) is not a good dimension for engineers in many fields, including mechanical engineering. We propose a unit of mass (Mg) that is compatible with the useful SI dimension of length (mm). The new subsystem comprises basic units; mm for length, Mg for mass, and s for second. The derived units are N for force, and MPa (N/mm^2) for stress etc. The individual need no conversion of sign which frequently leads to some fault result. Thus, we insist that the SI committee officially introduce the new subsystem for the wider and flawless use.

$$\begin{aligned} \mathbf{1N} &= \mathbf{1kg \cdot m/s^2} \\ &= \mathbf{1kg \cdot \frac{m}{s^2} \cdot \frac{1,000mm}{1m}} \\ &= \mathbf{1,000kg \cdot mm/s^2} \\ &= \mathbf{1Mg \cdot mm/s^2} \end{aligned} \qquad (7)$$

where Mg is compatible mass for mm in absolute system.

We also previously used a unit of mass (slugin) that is compatible with the useful dimension of length (in) in the ft-lb system. However, later, Dr. Norton [4] also independently proposed a unit [blob]. The English foot-pound-second system requires that length be measured in feet (ft), force in pounds (lbf), and time in seconds (sec). Mass is then derived from Newton's law as follows.

$$m = (Ft^2)/L \tag{8}$$

The units are pounds seconds squared per foot (=slug). The English inch-pound-second system requires that length be measured in inch (in), force in pounds (lbf), and time in seconds (sec). Mass is still derived from Newton's law, but the units are now pounds seconds squared per inch: (lb·s^2/in) = slugin = blob. The mass unit is slugin which is equal to 12 slug or one blob.

$$\begin{aligned} &\mathbf{1lbf = 1lbm \cdot \frac{\mathit{g}ft}{s^2} = 1slug \cdot ft/\mathit{s}^2} \\ &\mathbf{\Rightarrow slug(ft) = \mathit{g}lb_m = 32.2lbm} \\ &\mathbf{1lbf = 1lbm \cdot \mathit{g}ft/\mathit{s}^2 = 1slugin \cdot in/s^2} \\ &\mathbf{\Rightarrow slugin = 1lbm \cdot \mathit{g} \cdot \frac{ft}{in} = 386.4lbm} \end{aligned} \tag{9}$$

where slugin is proper or compatible mass in gravity system (**1slugin = 12slug**).

For MKS system,

$$\begin{aligned} \mathbf{1kgf} &= \mathbf{1kg \cdot \mathit{g}m/\mathit{s}^2 = 1slugm \cdot m/\mathit{s}^2} \\ &= \mathbf{1slugmm \cdot mm/\mathit{s}^2} \end{aligned} \tag{10}$$

$$\mathbf{\Rightarrow slugm = \mathit{g}kg = 9.81kg}$$

$$\mathbf{\Rightarrow slugmm = \mathit{g} \cdot \frac{m}{mm} \cdot kg = 9,810kg}$$

Figure 7 summarizes the unit systems. We usually use incompatible MKS, MKS, incompatible ft-lb, ft-lb and SI unit systems. In this study, we suggest using sub MKS, sub ft-lb and sub SI unit systems.

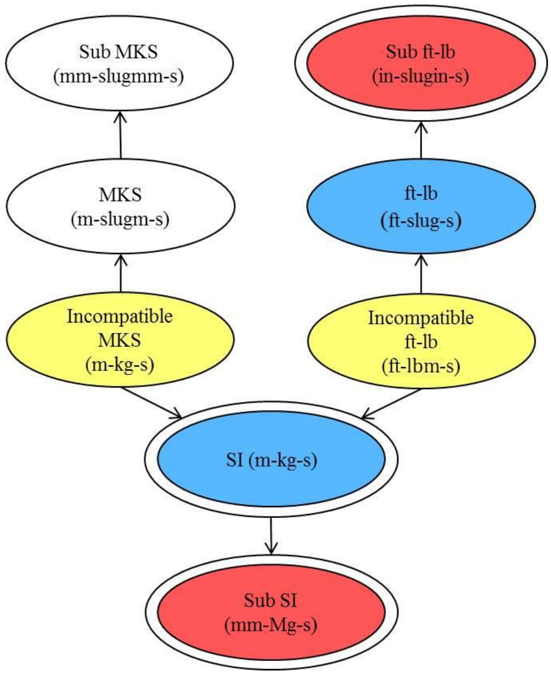

Figure 7. Diagram of unit systems

CONCLUSION

Five subjects that mechanical engineers deal with every day are treated to obtain insights into efficient usage and avoid misleading concepts. We summarize these considerations as follows.

1. The comprehensive and exact definitions of the renowned term 'stress' should be given. The term should be used in accordance with its exact definition.
2. Four signs of conventions are given in the first lecture on the Mohr's circle, and then a sign of convention is taken to proceed further. The engineer who knows all of the four systems will not be confused by the Mohr's circle systems found in other texts.
3. There are simple yet misleading concepts regarding the use of the contact-stress formula for the involute gear and pinion. The correct use of diameter *d* in the formula yields a result compatible to the laws of action and reaction.

4. Although there is an appropriate diagram for a tightened bolt joint under an external load, most texts adopt an inefficient and sometimes incomplete diagram for the explanation of an initially stressed bolt under a separating load.

5. Many engineers across the world use the SI system. However, mechanical engineers use millimeters instead of meters to measure length. When one uses millimeters as a derived length unit, he/she is likely to obtain incorrect results, especially in dynamics. Therefore, a new system, which is a subsystem of the SI system, is proposed. The new system uses the following basic units: mm, Mg, and sec, where the first m in 'mm' is not a separable prefix.

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