



Machine Design Series: Stress, Strain and Failure Considerations (Course #2)

An Online Continuing Education Course for Engineers

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Jyoti Mukherjee, P.E.

1. FBD, BMD, and SFD

Any machine consists of components that work in unison to transmit loads on the structure and create the ability to function properly. The components could be in series or in parallel to perform the required functions. Loads on the structure could be static, dynamic, or random by nature.

For example, loads on a machine could be cutting loads due to metal removal, gravity loads due to its weights, thermal loads due to temperature, dynamic loading due to centrifugal actions, etc. The components of any structure need to be strong enough to carry the external and internal forces, moments, and torque, without premature failure.

A setup for turning a part in a lathe is shown in Fig. 1. The component to be machined is held between a chuck and a tailstock as shown. The job piece rotates at N RPM with a torque, T lb-inch. Tailstock provides axial thrust, T_s , Lbs.

The turning tool removes metal as shown in the figure. Now, equal and opposite three-dimensional forces are created at the point of contact and these forces help the removal of metal from the job. To analyze the forces created, free body diagrams (FBD) are developed first as shown in Fig. 2. Forces, moments, and torques as shown in the diagram must be in equilibrium at any point in time.

In other words, applied external and internal forces must be equal and opposite to the reactionary forces to keep the component in equilibrium at any point in time. This concept must be understood properly to analyze any component.

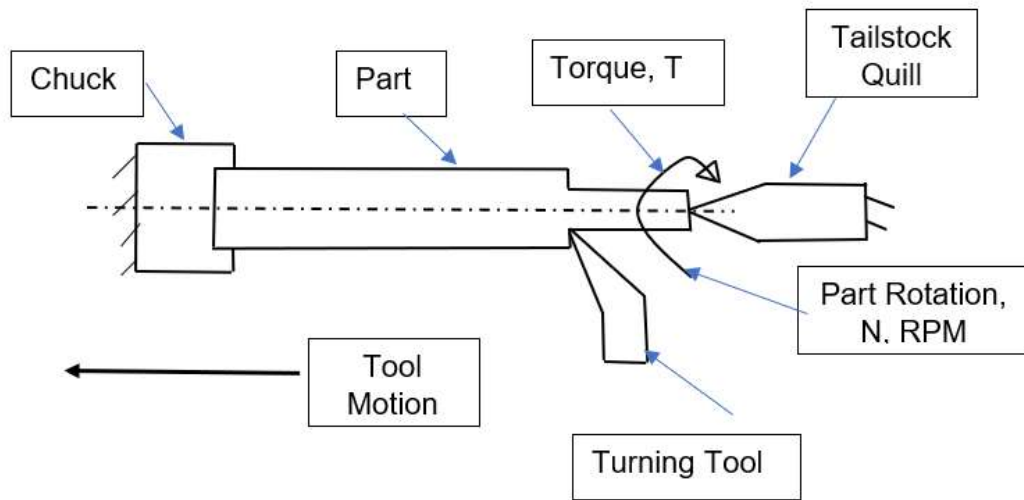
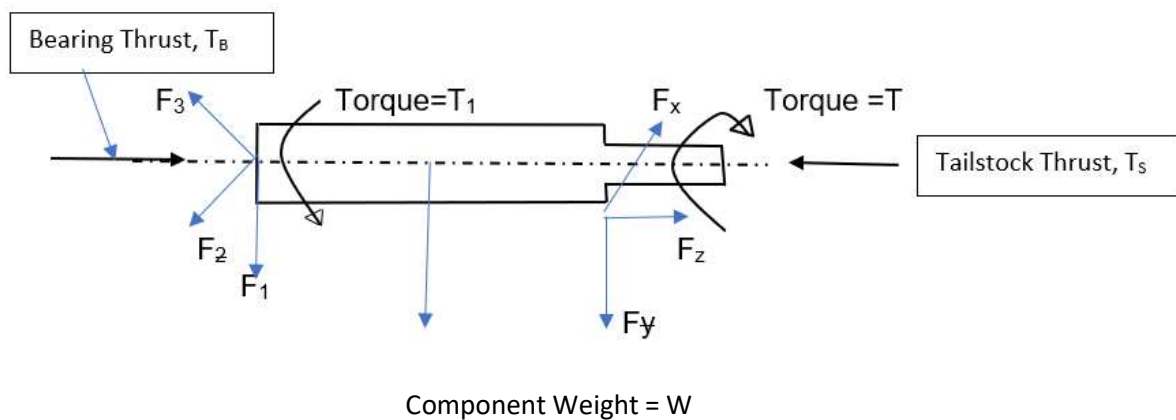


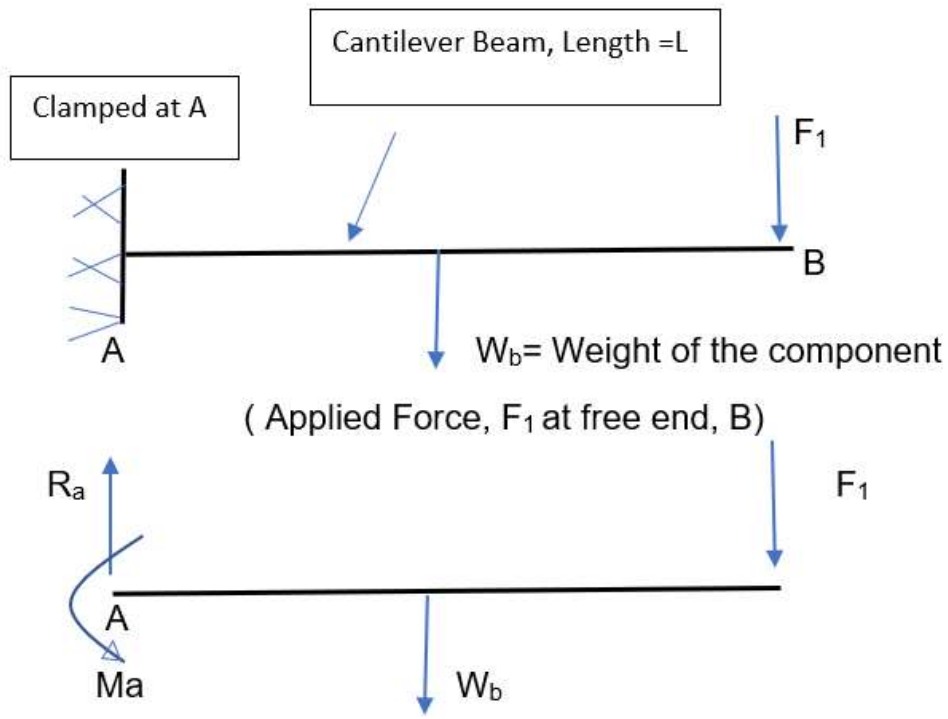
Fig. 1 Turning Tool Set up (Not to Scale)



Note: Bearing Thrust Force, T_s ; Bearing Reactionary Forces, F_1 , F_2 , and F_3 are equal and opposite to the forces, externally applied forces i.e., Weight Component, W , Cutting Forces, F_x , F_y , and F_z . All the forces, moments, and torques must be such that the FBD of the component remains in static or dynamic equilibrium.

Fig. 2 FBD of the component (Not to Scale)

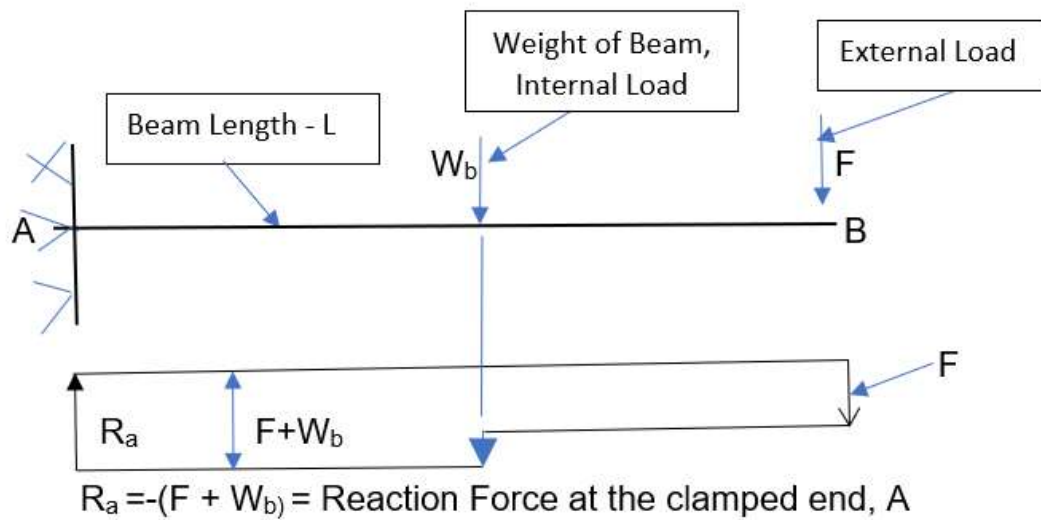
In a cantilever beam, one end is fixed, and another end is free to move when the load is applied as shown in Fig. 3. A force, F , is applied to the free end and the fixed end reacts to the externally applied force to keep the bar in equilibrium. Fixed end can resist bending and shear force loadings.



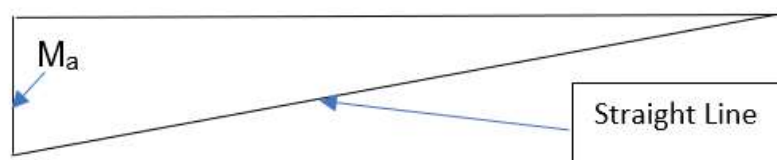
Here, $R_a = F_1 + W_b$ and $M_a = F_1 * L + W_b * 0.5 * L$

Fig. 3 FBD of a Cantilever Beam (Not to Scale)

Force Analysis of any system also needs another simple concept, called Shear Force Diagram (SFD) and Bending Moment Diagrams (BMD) for the beams of any structure. These concepts are very fundamental to stress-strain analysis. The following section will explain these principles in brief (See Fig. 4 also). Similar diagrams of different beam setups can be found in the reference books mentioned in the reference section. Examples of cantilever beams and a simply supported beam will be discussed below.



Shear Force Diagram (SFD) of Cantilever Beam

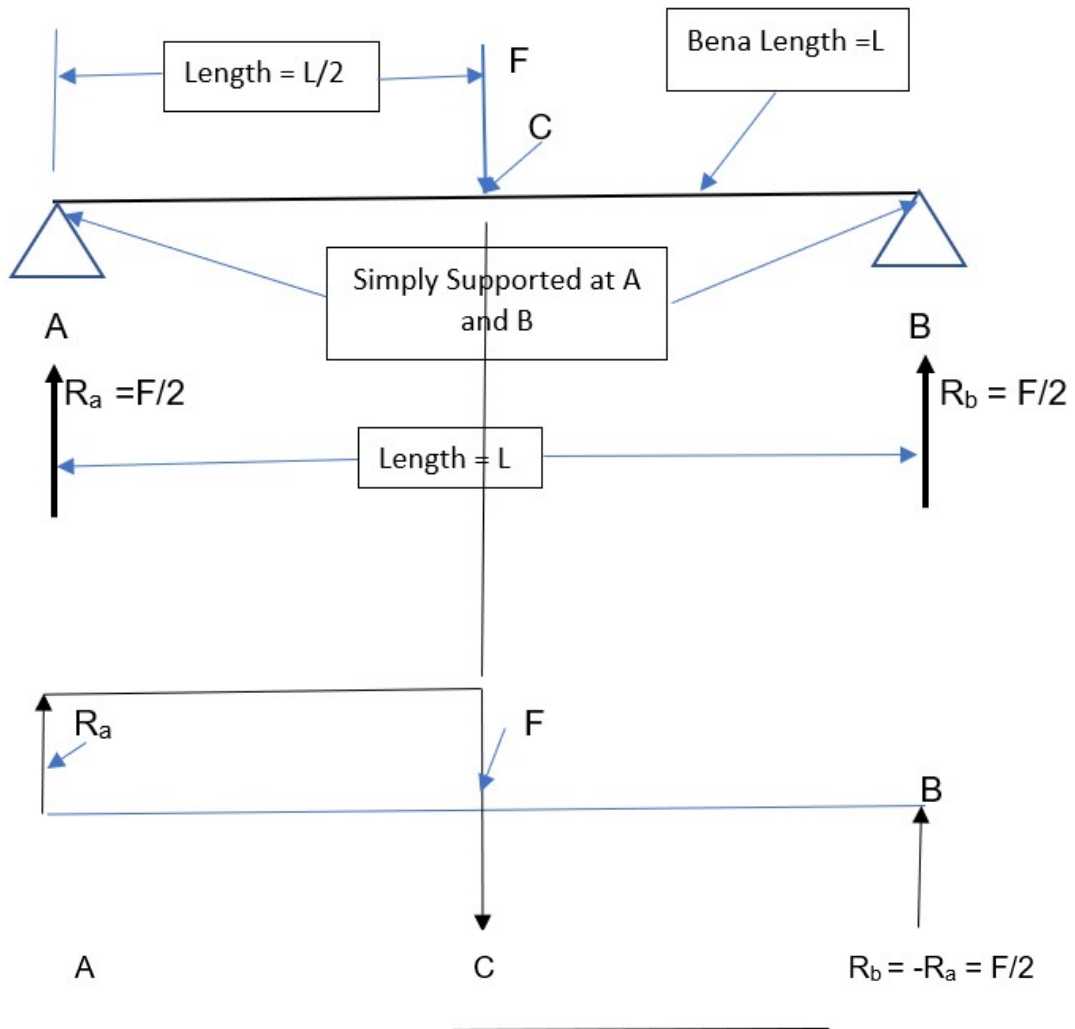


$M_a = F \cdot L + 0.5 \cdot L \cdot W_b = \text{Reactionary Moment at the clamped End, A}$

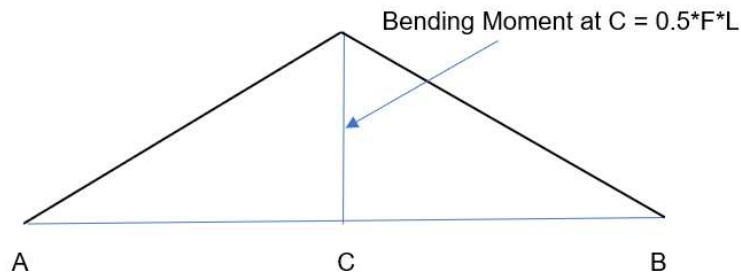
Bending Moment Diagram (BMD) of Cantilever Beam

Fig. 4 BMD and SFD for a cantilever Beam

The nature of the SFD and BMD for different setups depends on the types of loads, type of beam supports, location of loads with respect to the beams, and length of the beams. The typical loads could be single-point loads, distributed loads, a combination of these loads, axial loads, etc. These diagrams are very important to design such beams for various structures under static or dynamic loadings. Next, simple supported beams with their own load in the middle of the beam will be discussed to explain this concept again. (See Fig. 5 also). Simple support ends cannot resist bending moments. So, bending moments at the end is zero.



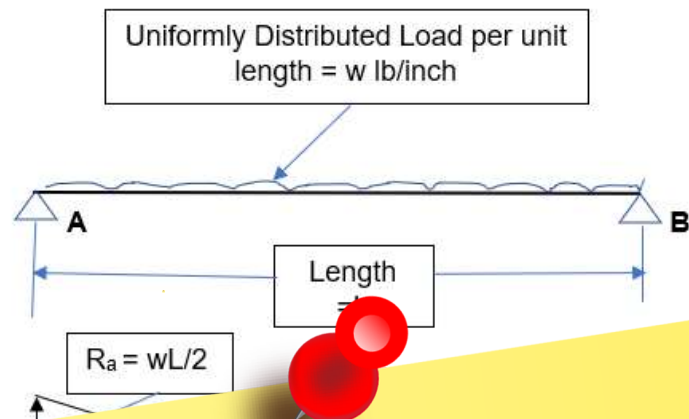
Shear Force Diagram (SFD) of Simply Supported Beam



Note: Moment at ends, A and B = 0

Bending Moment Diagram (SFD) of Simply Supported Beam

Fig. 5 BMD and SFD for a Simply Supported Beam



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Bendi

Fig

Distributed Load

As it has been mentioned earlier, simply supported beams can only resist shear force at ends and cannot take bending moment i.e., it is free to rotate at points A and B but cannot move. Similarly, a cantilever beam can resist both bending moment and shear forces, and deflection is total zero for cantilever beams against any load. A question arises as to why such diagrams are needed for analysis. The primary reason is to find shear force and bending moment at any point of the beam in between end supports.

Knowing the forces and moment at any cross-section, the section could be designed accurately to ensure the beam can withstand such loading without failure. The cross-section properties will be explained later in the section when necessary. The sectional properties of any beam could be cross-