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Development of a Method for Mechanical Strength Analysis of Pelletizing Machine

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Abstract: As the sources of fossil fuels are restricted and usage of them is resulted to GHG emission, it is necessary to use renewable energy sources as strong alternative for fossil fuel. Solid biomass is one of these renewable energy sources in order to produce heat and electric. In order to use solid biomass energy much more effectively it must be pelletized. Pelletizing is a mass and energy densification for materials with low bulk density such as sawdust, straw and other herbaceous energy crops. Pelletizing is a method of increasing the bulk density of biomass by mechanical pressure. The process assists to reduce transportation costs, provides better handling and feeding of the biomass and efficient storage with less dust formation. In the industrial scale, pelletizing of biomass is done by means of cylindrical pelletizing machines. Generally, these machines are manufactured by small scale companies. Samll scale pelletizing machine manufactures usully have not suffiicant knowlage and staff to run comprehensive mechanical strength analyses during machine design process. The objective of this study is to proper a simple program for mechanical strength analysis for main parts of cylindrical pelletizing machines.

Key words: Biomass, pelletizing, mechanical strength analysis

INTRODUCTION

Biomass is the third-largest energy resource in the world, after coal and oil (Bapat et al.,1997). Biomass was the main energy resource of the world's energy consumption until the mid-19th century. According the past 50 years, the consumption of biomass for energy purposes has decreased sharply, because of increasing in fossil fuel usage and technologies. Despite these, biomass still provides about 1,250 million tons of oil equivalents (Mtoe) and supplies about 14% of the World's annual energy consumption (Purohit et al., 2006; Werther et al., 2000; and Zeng et al., 2007). If the biomass consumption is managed properly, it offers many advantages. The most important advantages of biomass consumption are that they are renewable and sustainable, and can significantly reduce net carbon emissions when compared with fossil fuels. Many of the developed and industrialized nations carry out research and development activities to use biomass energy resource more efficiently. Because of these research and development activities, biomass is already a competitive resource for energy production in the USA and most of Europe. USA and Sweden obtain about 4% and 13% of their energy, respectively, from biomass (Hall et al., 1992).

One of the major limitations of biomass as energy source is its low density, typically ranging from 60– 80 kg/m^3 for agricultural straws and grasses and 200–400 kg/m^3 for woody biomass like wood chips (Sokhansanj and Fenton., 2006; Mitchell et al., 2007). These low densities often make biomass material difficult to store, transport, and utilize. When this type of low density biomass is co-fired with coal, the difference in density between biomass and coal causes problems in feeding the fuel into the boiler and reduces burning efficiencies.

In order to use biomass energy source effectively, the density of biomass must be increased.

Commercially, increasing the density of biomass by about tenfold and help overcome feeding, storing, handling, and transporting problems, is done by using pellet mills, extruder or briquetting presses. Pelletisation of biomass is a mass and energy densification for materials that possess low bulk densities such as sawdust, straw and other herbaceous energy crops. Pelletizing is a method of increasing the bulk density of biomass by mechanical pressure. The typical bulk density of biomass chips is less than 150 kg/m^3 while that of wood pellets is typically over 600 kg/m^3. The process reduces transportation costs, provides better handling and feeding of the biomass and efficient storage with less dust formation.

There are two main types of pellet presses: ring die and flat die. In general the die remains stationary and the rollers rotate. The various components of commercial pellet mill are shown in Figure 1.

Figure 1. A typical commercial pelletizing machine (Kocamaz Makina)

In pelletizing equipment, the incoming feed from the feeder is delivered to the conditioner for addition of steam or binders such as molasses to improve the pelletizing process. The feed from the conditioner is discharged into the pelletizing die. Biomass pellets are formed in pelletizing chamber by compacting and forcing through die openings by rollers in a mechanical process.

In the pelletizing die, the feed material is pressed through open-ended cylindrical holes (dies) made in the periphery of a ring. One to three small rotating rolls push the feed material into the die holes from inside of the ring towards the outside of the ring. The skin friction between the feed particles and the wall of the die resists the free flow of feed and thus the particles are compressed against each other inside the die to form pellets. One or two adjustable knives placed outside the ring cut the pellets into desired lengths. As it illustrated later in the industrial scale, pelletizing of biomass is done by means of cylindrical pelletizing machines. Generally, these machines are manufactured by small scale company. Therefore, comprehensive mechanical strength analyses are not done during machine design process. The main objective of this research is to proper a simple method for mechanical strength analysis for main parts of cylindrical pelletizing machines.

MATERIALS and METHOD

As it is known, commercial pelletizing machine is consisting of; feed hopper, conditioner and feeding unit, pelletizing chamber and it's equipments (such as pelletizing cylindrical die, pelletizing rollers, pellet roller shaft and bearings, pellet die shaft and bearings and drive mechanism), pelleted material cutting and exist unit and chassis.

As, in developing countries pelletizing machine are designed and manufactured by small scale companies, and these companies have not efficient knowledge and experience and expert staff for mechanical strength analysis of pelletizing machine parts. Hence, some critical problems are occurred during pelletizing machine operation after manufactıring. According to statistical data and experience, it is emerged that the most mechanical difficulties of pelletizing machine are occurred on pellet roller shaft and pellet die shaft and their bearings.

Hence in this study, in order to reduce errors during biomass pelletizing machine design, a simple program for mechanical strength analysis of pelletizing machine was developed. By means of this simple program, the mechanical strength analysis of roller and pellet die shaft were done. In order to execute mechanical strength analysis of pellet roller and pellet die shafts, it is necessary to known the loads which are applied on roller and die shafts during pelletizing machine operation. The value of these loads which are occurred during operation of pelletizing machine can be evaluated from experience and pelletizing theory principles.

As it is known, in the mechanical strength analysis it is desired that the maxsimum values of loads consider for calculation. Therefore, in this study it is assumed that the rolling resistanse force values for top roll is half of bottom rolls. Also, it is mentioned that the amount of pelletizing load on bottom roll is two times of top roll. These loads are shown in Figure 2.

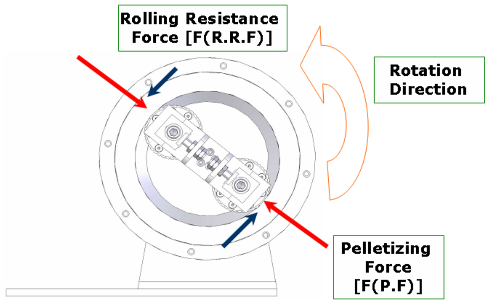

Figure 2. Loads acting on pelletizing machine

Pellet Roller Shaft Analysis: To execute mechanical strength calculations of pellet roll shaft, in the first step it is necessary to determine the free diagrams of shaft. Therefore, according to the loads which are applied on shaft, the reaction forces and moments of shaft must be calculated. The loads which are acting on pellet roller shaft are shown in Figure 3.

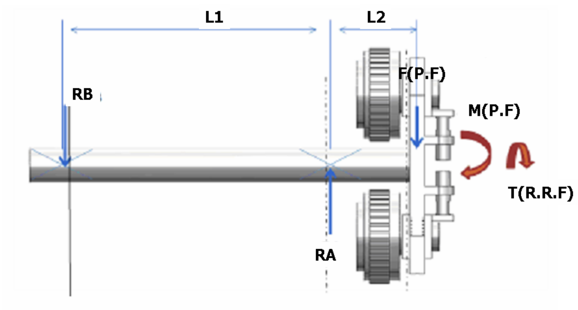

Figure 3. Applied load on pellet roll shaft

These loades descriptions are introduced as following:

RA & RB: Reaction loads on shaft bearing place (N)
F (P.F): Total pelletizing force on shaft (N)
M (P.F): Bending moment on shaft (Nm)
T (R.R.F): Torsion moment on shaft (Nm)

Also, it is needed to determine the area and the second moment of area of shaft on different section of shaft. Related calculations are as follows;

$$A = \pi R^2 ; I = \frac{1}{4}\pi R^4 ; J = \frac{1}{2}\pi R^4 \qquad (1)$$

Where;

"R" is the radius of shaft on selected section (m),
"I" and **"J"** are the second moment of area of shaft on selected section (m^4),
"A" is the area of shaft on selected section (m^2).

The second step in mechanical strength analysis of pellet roll shaft is to determine internal force and moment which are applied on different sections of shaft. These internal loads are illustrated in Figure 4. As it is shown in Figure 4, the amount of torsional moment that is applied on shaft is constant on all section on shaft. Also, the maximum values of shear force and bending moment which are applied on shaft are taken place on bearing point near the rollers. Therefore, the mechanical strength analysis of shaft must be done according to this section of shaft.

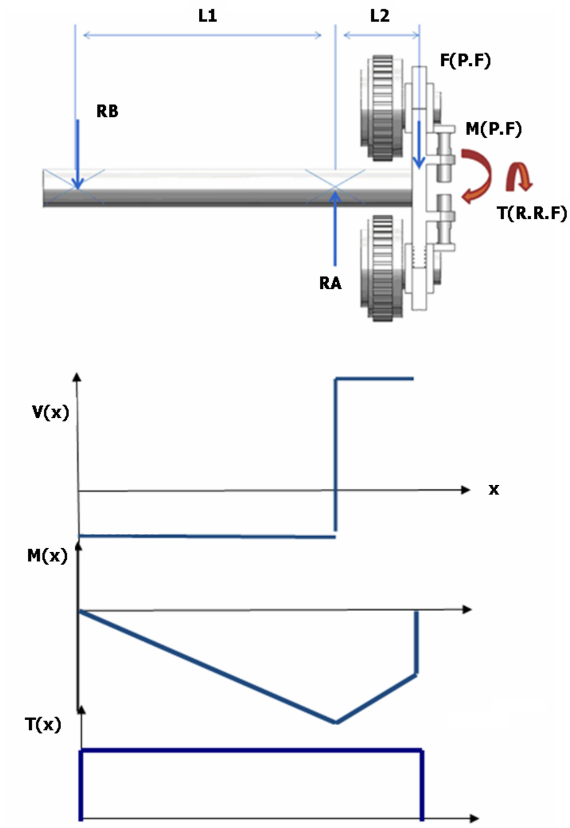

Figure 4. Internal load on pellet roll shaft

In order to carry out mechanical strength analysis of shaft on selected section, it can be assumed two different elements "A" and "B" on this section. The diameter of shaft and location of elements on selected section of shaft are shown in figure 5.

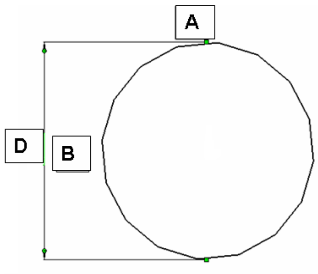

Figure 5. ''A'' & ''B'' element position on shaft

As it is shown in Figure 5, the element ''A'' is located on the top of shaft that is the farthest distance from the neutral line of shaft. This element is subjected by bending and torsional moment which is caused to normal and shear stress, respectively (Fig.6). The normal and shear stresses are calculated by the following method.

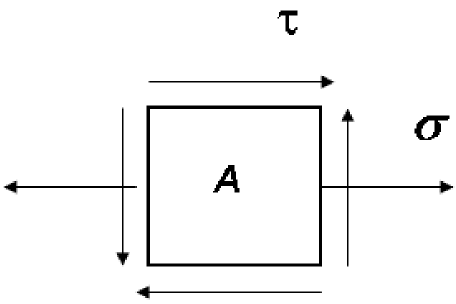

Figure 6. Loads on Element ''A''

$$\sigma = \frac{-M.R}{I} \tag{2}$$

$$\tau = \frac{T.R}{J} \tag{3}$$

Where;
''M'' is the internal bending moment applied on selected section of shaft (Nm),
''T'' is the internal torsional moment applied on selected section of shaft (Nm),
''σ'' is the normal stress which is occered on selected element of shaft (MPa),
''τ'' is the shear stress which is occurred on selected elements of shaft (MPa).

As it is shown in Figure 7, element (B) is subjected to shear force and torsional moment which is caused to shear stress on place of the element.

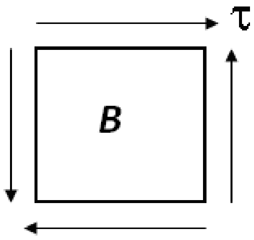

Figure 7. Loads on Element ''B''

The strength analysis for this element is explained below.

$$\tau = \frac{4}{3}\left(\frac{V}{A}\right) \tag{4}$$

$$\tau = \frac{T.R}{J} \tag{5}$$

Where;
''V'' is the internal shear force applied on selected section of shaft (N),
''τ'' is the shear stress which is occurred on selected elements of shaft (MPa).

As in mechanical strength analysis of shaft, maximum shear strength theory is used. The maximum shear stress which are occurred on elements (A) and (B) must be compared with each other. The greater value must be considered for mechanical strength analaysis calculation.

In this study, during mechanical strength analysis the maximum shear stress method was used. The analysis which applied on element is as follows;

$$\tau_{mox} = \sqrt{(\frac{\sigma_x - \sigma_y}{2})^2 + (\tau_{xy})^2} \tag{6}$$

During the manufacturing of the pellet roll shaft, it can be used different kind of steel as like as 1050, 4140 or 8620. The factor of safety of shaft can be calculated as below with consideration to the yield stress of material.

$$F.S. = \frac{S_y}{2\tau_{mox}} \tag{7}$$

Where;

"F.S." is the safty factor of selected section of shaft,
"Sy" is the yield stress of material which is used in shaft manufacturing (MPa),
"τ_{Max}" is the maximum shear stress which is occurred on selected elements of shaft section (MPa).

If the calculated value for safety factor of shaft is larger than 1.8, the shaft material and its geometric properties are adequate for pelletizing machine operation.

Pellet Die Shaft Analysis: To execute mechanical strength calculations of pellet die shaft, it is necessary to determine the free diagrams, area and the second area moment of inertia of shaft. Pellet die shaft dimension is shown in Figure 8. Related calculations are as follows;

$$A = \pi(R_O^2 - R_i^2)\ ;\ I = \frac{1}{4}\pi(R_O^4 - R_i^4)\ ;\ J = 2I \qquad (8)$$

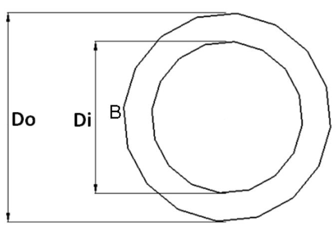

Figure 8. (A) & (B) element position on shaft

Where;
"R_o & R_{in}" are the outer and inner radius of shaft on selected section (m).

According to pelletizing machine operation the forces and moments which are applied on pellet die shaft is shown in figure 9. The reaction force and moments can be determined as bellow.

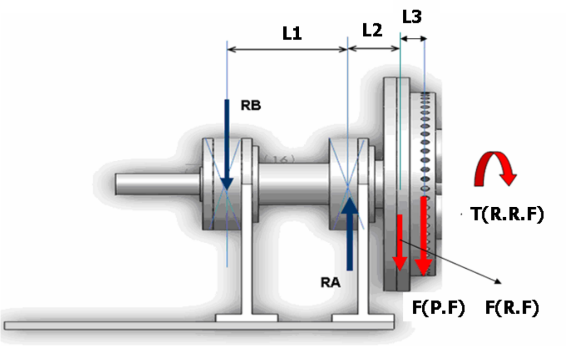

Figure 9. Applied load on pellet die shaft

The descriptions of these loads are introduced as following:

RA & RB: Reaction loads on shaft bearing place (N)
F (P.F): Total pelletizing force on shaft (N)
F (R.F): Force applied to die shaft from roll shaft (N)
T (R.R.F): Torsion moment on shaft (Nm)

The second step in mechanical strength analysis is to determine internal force and moment which are applied on different section of shaft. The values of these loads are illustrated in Figure 10.

As it is shown, the maximum values of shear force and moments that are applied on shaft are taken place on bearing near the rollers. Therefore, the mechanical strength analysis of shaft must be done according to this section of shaft.

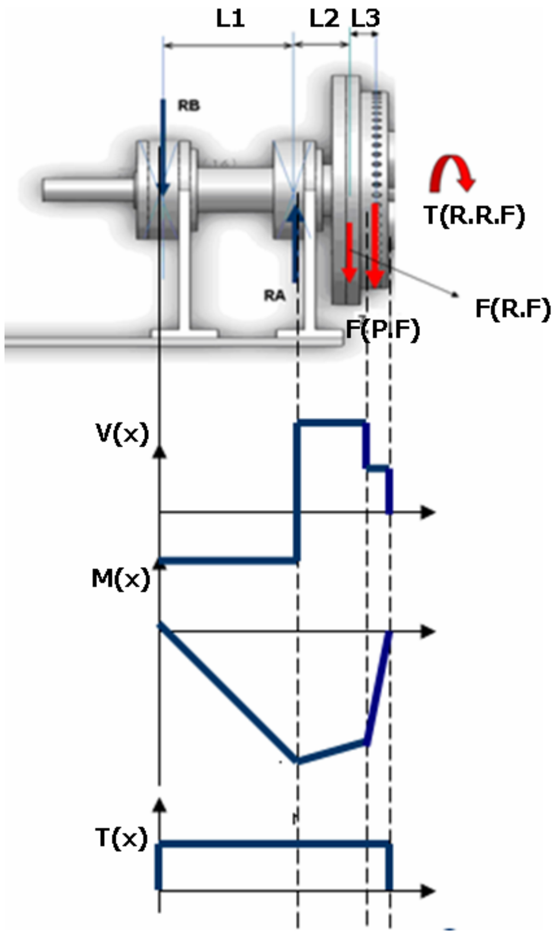

Figure 10. Internal load on pellet die shaft

According to ''A'' element's positon on the top of the shaft (Fig.8), this element is subjected by bending and torsional moment which are caused normal and shear stress, respectively. Also, the ''B'' element is subjected to shear force and torsional moment which is cacused to shear stress on element.

The normal and shear stresses which are occured on ''A'' element can be calculated by the following method (Fig.11).

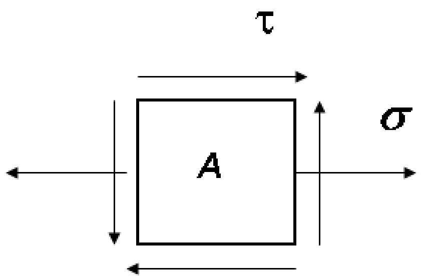

Figure 11. Loads on Element ''A''

$$\sigma = \frac{-My}{I} \quad (8)$$

$$\tau = \frac{T.r}{J} \quad (9)$$

Also, as it is shown in Figure 12, the element ''B'' is subjected to shear force and torsional moment which is caused to shear stress on place of the element.

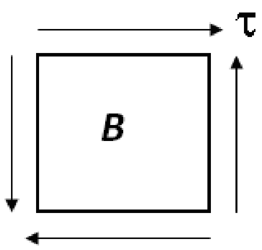

Figure12. Loads on Element ''B''

The strength analysis about the element is explained below.

$$\tau = \frac{4}{3}\left(\frac{V}{A}\right) \quad (10)$$

$$\tau = \frac{T.r}{J} \quad (11)$$

As it was mentioned before, in mechanical strength analysis of shaft, the maximum shear stress theory will be used. Therefore, the maximum shear stress which is occurred on elements ''A'' and ''B'' must be compared with each other. The greater value must be considered for mechanical strength analysis calculation.

According to the maximum shear stress method the maximum shear stress which is applied on elements is calculated as below.

$$\tau_{mox} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + (\tau_{xy})^2} \quad (12)$$

During the mechanical strength analysis, the safety factor equation can be used like as below.

$$F.S. = \frac{S_y}{2\tau_{mox}} \quad (13)$$

In manufacturing of the pellet roller shaft, it can be used different kind of steel as like as 1050, 4140 or 8620. Accordind to the yield stress of material used in manufacturing of shaft, loads applied to the shaft and desired diameter for shaft the safety factor value for pellet die shaft of pelletizing machine can be calculated easily.If the safety factor which is calculated is bigger than 1.8, it means that the proper shaft diameter is selected.

In this research, ''Microsoft Excel Software'' was used to generate simple program for mechanical strength analysis of pelletizing machine' shafts.

RESULTS and DISCUSSION

As a result of this study, a simple program for static mechanical strength analysis of pelletizing machine's shafts was developed.

By usuing this simple calculation program the mechanical strength analysis was conducted for a prototip pelletizing test machine. The forces which are acting on pelletizing machine and some dimension of machine are shown in Figure 13. These loads are obtained by experimental and teoreical methods. The geometrical properties and (external/internal) loads which are applied to machine parts illustrated in Figure 14, 15.

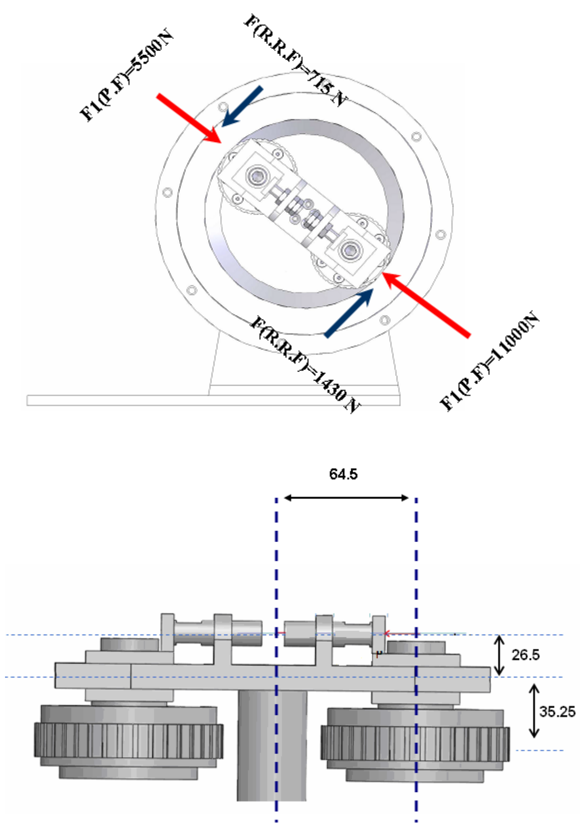

Figure 13. Loads acting on pelletizing machine

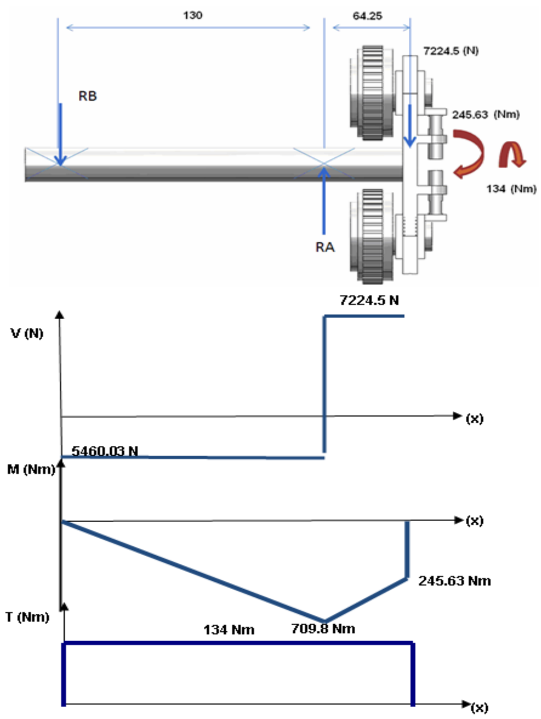

Figure 14. Loads on pellet roll shaft

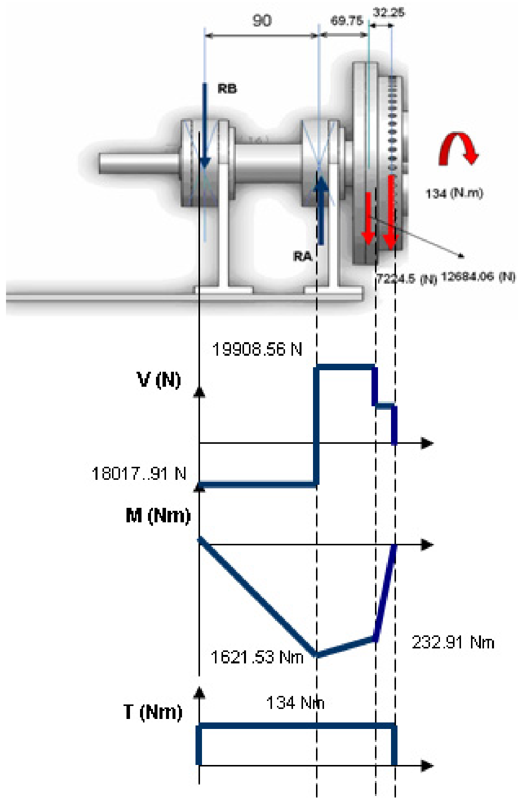

Figure 15. Load on pellet die shaft

According to the results which are obtained from calculating program, the safety factor value for pellet roll shaft diameter and pellet die shaft's diameter are obtained as, 1.84 and 3.64, respectively.

CONCLUSIONS

The followings were concluded from the study:

- As a result of this study, the pelletizing machines which are designed and constructed according to the experimental data, can be designed by using tha data which are obtained from this simple program.
- Using this simple program will lead the smale scale pelletizing machie producer to use the material with optimum dimension.
- Usage of this program by small scale pelletizing machine manufacturer can assist to decrease pelletizing machine cost. Low cost and economical price for pelletizing machine means low cost energy or pelleted material.
- As it mentioned before, the program which is developed in this study is able to done static mechanical strength. But, the loads that are

applied on pelletizing machie parts are dynamic. Therefore it is desired to develop a program that can be able to realize dynamic mechanical strength analysis.

- This simple program calculates the mechanical strength of pellet die shaft and pellet roll shaft. During later studies, it is desired to develope a comprehensive program for mechanical analysis of all parts of pelletizing machine.

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