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Development of MATLAB Program for Merchant's Circle Diagram

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Abstract -: *A merchant circle diagram is made as a graphical representation of the number of forces acting on a workpiece when it is subjected to orthogonal cutting. Using this MATLAB program, one can find the theoretical forces, various angles, coefficient of friction, and power consumption inflected on a metal piece when the following inputs are provided: Rake angle of the tool, Cutting force, axial force, feed rate, RPM, workpiece diameter, shear strength of the material and chip thickness. Using MATLAB will ensure faster calculations and in turn, a reduced calculation time, also the elimination of human error will happen with higher accuracy.*

***Key Words*: Cutting forces, Cutting velocity, Cutting power, MATLAB, Metal cutting, Merchant circle diagram,**

1. INTRODUCTION

Metal cutting can be defined as the process of removing excess material from block material to get the required shape/finished product.

- Types of metal cutting processes:

1) Orthogonal cutting

2) Oblique cutting

1.1 Orthogonal cutting and oblique cutting

Table – 1: Difference between Orthogonal and Oblique cutting

Orthogonal Cutting	Oblique Cutting
(1) The cutting edge of the tool is perpendicular to the cutting with the velocity factor.	(1) The cutting edge is inclined at an angle to the current velocity factor.
(2) The cutting edge clears the width of the workpiece on either end.	(2) The cutting edge may not clear the width of the workpiece on either end.
(3) The chip flows over the tool face.	(3) The chip flows on the tool face.
(4) Only two components of the cutting forces are acting on the cutting tool.	(4) Three components of the cutting forces are(1) acting on the cutting tool.
(5) Tool is perfectly sharp	(5) Tool is not perfectly Sharp.
(6) Only one cutting edge in action.	(6) More than one cutting edges are in action.

1.2 Conditions required for successful metal cutting operations:

(1) Relative motion between the cutting tool and workpiece.

(2) The cutting tool must be harder than the workpiece to ensure safe operation during machining.

(3) Workpiece and cutting tool must be held rigidly into work holding devices and jigs/fixtures to ensure safety.

(4) The sharp cutting edge of cutting tool to ensure vibration-free and hassle free machining operation.

(5) Optimum speed, feed, and depth of cut for efficient cutting operation.

1.3 Aspects of cutting forces concerned in metal cutting

(1) Magnitude of cutting forces and their components

(2) Direction and locations of action of those forces

(3) Pattern of the forces: Static/Dynamic

1.4 The need for analysis of cutting forces:

(1) To determine machine tolerances and design of stiffness.

(2) Whether the workpiece can withstand the cutting force or not can be determined.

(3) In a study of behavior and machinability characterization of the workpiece.

(4) Estimation of cutting power consumption, which also enables selection of the power source(s) during the design of the machine tool.

1.5 Benefits of determining cutting forces:

(1) For the estimation of cutting power consumption and selection of power sources based on requirements during the machine tool design process.

(2) To facilitate the structural design of machine tools, fixtures, and tooling system.

(3) To determine the effects of various machining parameters on produced cutting forces.

(4) To monitor conditions of machine tools and cutting tools.

2. Merchant circle diagram

Merchant's circle diagram is constructed to ease the analysis of cutting forces acting during orthogonal cutting of workpiece.

2.1 Assumptions made while preparing the Merchant's circle diagram

(1) Tool edge is sharp.

(2) The workpiece material undergoes deformation across a shear plane.

(3) There is a uniform distribution of normal and shear stress on the shear plane.

(4) The workpiece material is rigid and perfectly plastic.

(5) The shear angle adjusts itself to minimum work.

(6) The friction angle remains constant and it is independent of shear angle.

(7) The width of the chip remains constant.

(8) There are no sideways of the flow of the chip.

(9) The cutting velocity always remains constant.

(10) Only continuous chips are produced.

(11) No built-up edge is formed.

(12) No consideration is made of the inertia force of the chip.

(13) The behavior of the chip is like that of a free-body which is in the state of stable equilibrium under the action of two resultant forces which are equal, opposite & collinear.

2.2 Advantages of Merchant's circle diagram

(1) Easy, quick, and reasonably accurate determination of several other forces from a few known forces involved in machining.

(2)Friction at chip tool interface and dynamic yield shear strength can be easily determined.

(3)Equations relating to the different forces are easily developed.

2.3 Disadvantages of Merchant's circle diagram

(1) Merchant's circle diagram (MCD) is only valid for orthogonal cutting.

(2) By the ratio, F/N, the MCD gives the apparent (not actual) coefficient of friction.

(3) It is based on a single shear plane theory.

3. MATLAB program inputs required and outputs shown

The MATLAB program takes inputs from the user and they are as follows:

(1)Cutting force, Fc, in Newton

(2)Thrust force, Ft, in Newton

(3)Rake angle of the tool, a, in radian

(4)Shear plane angle, b, in radian

(5)Cutting velocity, Vc, in ft/min

The outputs obtained by this program are Cutting ratio (Rc), Resultant force(R), Frictional force between tool and chip (F), Normal force (N), Shear force (Fs), Force normal to the shear plane (Fn), Coefficient of friction (Mu), Shearing velocity (Vs), Frictional velocity (Vf), Total cutting power (Pc), Total shearing power (Ps) and Total power lost due to friction (Pf).

3.1 MATLAB program for the Merchant's circle diagram:

MATLAB online is used for the programming of this code. Following is the MATLAB program for Merchant's circle diagram as per the required inputs mentioned above:

```
%taking inputs from user

Fc = input("Please enter the value of Fc, Cutting force in Newton");

Ft = input("Please enter the value of Ft, Thrust force in Newton");

a = input("Please enter the value of a, rake angle in radian");

b = input("Please enter the value of b, shear plane angle in radian");

%formulating and displaying results

R = sqrt ((Fc * Fc) + (Ft * Ft));

fprintf ('\nThe value of resultant force is %f N', R);

F=(Ft * cos(a))+(Fc * sin (a));
```

fprintf('\nThe value of frictional force between tool and chip is %f N',F);

N=(Fc * cos(a))-(Ft * sin(a));

fprintf('\nThe value of normal force is %f N',N);

Fs = (Fc*cos(b)-Ft*sin(b));

fprintf('\nThe value of shear force is %f N',Fs);

Fn = (Fc*cos(b)+Ft*sin(b));

fprintf ('\nThe value of force normal to shear plane is %f N',Fn);

Mu = (F/N);

fprintf ('\nThe value of coefficient of friction is %f N',Mu);

Vc = input("\nEnter the value of Vc, cutting velocity in ft/min or press enter twice to end");

Vs = Vc * cos(a)/(cos (b-a));

fprintf('\nThe value of shearing velocity is %f ft/min',Vs);

Vf = Vc * sin (b)/(cos(b-a));

fprintf ('\nThe value of frictional velocity is %f ft/min',Vf);

Pc = (Fc*Vc)/33000;

fprintf ('\nThe total cutting power in horsepower is %f', Pc);

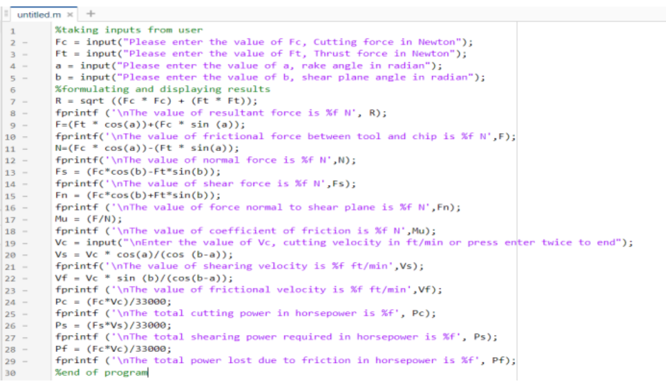
Ps = (Fs*Vs)/33000;

fprintf ('\nThe total shearing power required in horsepower is %f', Ps);

Pf = (Fc*Vc)/33000;

fprintf ('\nThe total power lost due to friction in horsepower is %f', Pf);

%end of program



```
untitled.m
%taking inputs from user
Fc = input("Please enter the value of Fc, Cutting force in Newton");
Ft = input("Please enter the value of Ft, Thrust force in Newton");
a = input("Please enter the value of a, rake angle in radian");
b = input("Please enter the value of b, shear plane angle in radian");
%formulating and displaying results
R = sqrt ((Fc * Fc) + (Ft * Ft));
fprintf ('\nThe value of resultant force is %f N', R);
F=(Ft * cos(a))+(Fc * sin (a));
fprintf('\nThe value of frictional force between tool and chip is %f N',F);
N=(Fc * cos(a))-(Ft * sin(a));
fprintf('\nThe value of normal force is %f N',N);
Fs = (Fc*cos(b)-Ft*sin(b));
fprintf('\nThe value of shear force is %f N',Fs);
Fn = (Fc*cos(b)+Ft*sin(b));
fprintf ('\nThe value of force normal to shear plane is %f N',Fn);
Mu = (F/N);
fprintf ('\nThe value of coefficient of friction is %f N',Mu);
Vc = input("\nEnter the value of Vc, cutting velocity in ft/min or press enter twice to end");
Vs = Vc * cos(a)/(cos (b-a));
fprintf('\nThe value of shearing velocity is %f ft/min',Vs);
Vf = Vc * sin (b)/(cos(b-a));
fprintf ('\nThe value of frictional velocity is %f ft/min',Vf);
Pc = (Fc*Vc)/33000;
fprintf ('\nThe total cutting power in horsepower is %f', Pc);
Ps = (Fs*Vs)/33000;
fprintf ('\nThe total shearing power required in horsepower is %f', Ps);
Pf = (Fc*Vc)/33000;
fprintf ('\nThe total power lost due to friction in horsepower is %f', Pf);
%end of program
```

Fig - 1: MATLAB program for Merchant's circle diagram

3.2 Results for the program mentioned above:

The following inputs were taken to find out the results:

Fc=100 N, Ft=120N, a=0.17 radian, b=0.5 radian and Vc=200 ft/min.

The results are as follows:

Please enter the value of Fc, Cutting force in Newton

100

Please enter the value of Ft, Thrust force in Newton

120

Please enter the value of a, rake angle in radian

0.17

Please enter the value of b, shear plane angle in radian

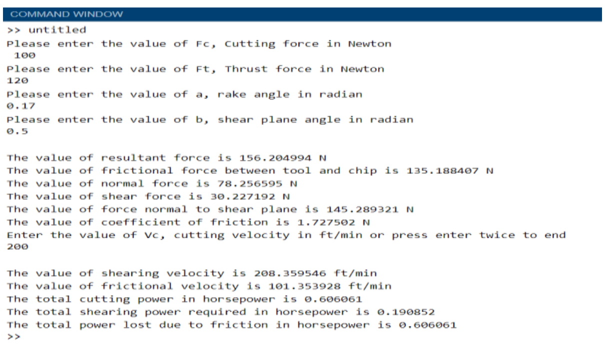
0.5

The value of resultant force is 156.204994 N
The value of frictional force between tool and chip is 135.188407 N
The value of normal force is 78.256595 N
The value of shear force is 30.227192 N
The value of force normal to the shear plane is 145.289321 N
The value of the coefficient of friction is 1.727502 N
Enter the value of Vc, cutting velocity in ft/min, or press enter twice to end

200

The value of shearing velocity is 208.359546 ft/min
The value of frictional velocity is 101.353928 ft/min
The total cutting power in horsepower is 0.606061
The total shearing power required in horsepower is 0.190852
The total power loss due to friction in horsepower is 0.606061

The image of the same result is shown below:



```
COMMAND WINDOW
>> untitled
Please enter the value of Fc, Cutting force in Newton
 100
Please enter the value of Ft, Thrust force in Newton
120
Please enter the value of a, rake angle in radian
0.17
Please enter the value of b, shear plane angle in radian
0.5

The value of resultant force is 156.204994 N
The value of frictional force between tool and chip is 135.188407 N
The value of normal force is 78.256595 N
The value of shear force is 30.227192 N
The value of force normal to shear plane is 145.289321 N
The value of coefficient of friction is 1.727502 N
Enter the value of Vc, cutting velocity in ft/min or press enter twice to end
200

The value of shearing velocity is 208.359546 ft/min
The value of frictional velocity is 101.353928 ft/min
The total cutting power in horsepower is 0.606061
The total shearing power required in horsepower is 0.190852
The total power lost due to friction in horsepower is 0.606061
>>
```

Fig – 2: Results for the given program

4. Conclusion

It can be concluded from the above program and results that this MATLAB program is correct and the program can be run on the MATLAB software/MATLAB online without any errors and the results are obtained quickly and accurately.

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