

DEVELOPMENT OF A HIGH SPEED ABRASIVE CUTTING MACHINE

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ABSTRACT

A high speed abrasive cutting machine was designed and developed. The abrasive wheel of 4mm thickness was used and the speed was 2500 rpm. It is driven by an electric motor having a power of about 3.67 kW. Tests results on the machine showed that it can cut 25mm and 60mm mild steel rods in 7.5s and 21.3s respectively; 25mm and 60mm stainless steel rods in 15.3s and 136.7s respectively. It was discovered from the tests that depending on the length of cut and material being cut, the high speed abrasive cutting machine was more efficient, in terms of cutting time, than the power hacksaw. The grinding/wear ratio was also dependent on the material being cut and the length of cut.

Keywords: *Abrasive wheel, discontinuous chip cutting, development, machine, high speed.*

1.0 INTRODUCTION

Saws are amongst the most common of machine tools and they are used in contouring and cutting off. There are three basic types of saws: hacksaw, circular and band saw. Circular saws are made of three types: metal saws, steel friction disks and abrasive disks. Circular saw blades are economical methods used for cut-off operations that require dimensional accuracy and a good surface finish (Sarwar et al, 1996; Zohdi et al., 2006). Oberg and Jones (1996) classified the cut-off machines into types which include simple machines which are used to cut one piece at a time, production machines used for many purposes such as making angle-cuts and plate cut-offs, and those used to cut large and tough materials. Sarwar et al, (1996) showed that the machinability of nickel based alloys are variable and relatively poor and also noted that high speed saw blades

were not suitable for machining certain types of nickel based alloys due to high localized temperatures generated which cause plastic deformation of tool and rapid rates of wear.

Abrasive cutting was initially regarded as a tool room method only but it has now grown to be a high-speed production operation, often preferable to steel saws, shears and flame cutting from the point of view of economy. Closer tolerances are achieved, eliminating subsequent finishing operation (Sahu and Sagar, 2006). Abrasive disks are mainly aluminium oxide grains or silicon carbide grains bonded together. They are used to cut ferrous and nonferrous metal (Zohdi et al, 2006). With abrasive parting-off there is no danger of work hardening of the work prior to the cutting action as is the case with other forms of cutting methods.

Jain (2008) described the abrasive cut-off sawing machine using abrasive cutter as a special grinding machine. Radford and Richardson (2007) suggested, however, that the abrasive wheel can be regarded and modelled

as a milling cutting tool with many teeth. The abrasive wheel has also been classified based on the abrasive grain types and the bonding materials. Gill (2005) and Jain (2008) classified abrasives into natural abrasives and manufactured abrasives. Natural abrasives include sand stone, garnet, flint, emery, quartz and corundum while manufactured abrasives are made from synthesized chemical compounds. Rajgopalan (1970) classified the bonding materials as vitrified bond made of clay or feldspar, resinoid bond made of synthetic resins, rubber bond, shellac bond, silicate bond and metal bond.

As an advantage over the conventional cutting method, the abrasive wheel has been noted to cut materials without distortion while cut surfaces are with minimum blur and better surface finish. In addition to this the abrasive cutting process does not require coolants, loses lesser amount of power, cuts faster and gives a better heat diffusivity property (Blackburn, 2000). Sahu and Sagar (2002) and Sahu (2001) also noted that many drawbacks of conventional parting-off wheel such as high wear ratio, high cutting zone temperature, premature failure of wheel due to low mechanical strength have been eliminated by developing a fibre glass/epoxy reinforced composite parting-off wheel. However, the cutting disk reduces after each cut is made due to fracture of abrasive which comes in contact with the metal but this creates a new cutting edge which keeps the cutting operation smooth (Blackburn, 2000).

The progress of the abrasive cutting machine is at a crest that is unprecedented by any other cutting-off technique (Shaw, 1975). This work is aimed at developing a high speed abrasive cutting machine and evaluating the machine for performance.

2.0 MATERIALS AND METHODS

This design considers the abrasive cutter primarily as a grinding wheel following Jain (2008) and secondarily as a milling cutting tool as suggested by Radford

and Richardson (2007). The components of the high speed abrasive cutting machine include the frame and upper platform, the handle and stopper, machine vice, electric motor, pulley, shafts and housing, cutting disk, bolts and nuts, bearings and transmission belts (Figure 1) .

2.1 Operation of the High Speed Abrasive Cutting Machine

The high speed abrasive cutting machine, shown in Figure 1 and Plate 1, operates on a similar principle as other machine tools, particularly the grinding and the milling machine. It has a rotating tool (the abrasive cutting wheel) which is carried on one end of a lever, and operated by a pulley which receives transmission from an electric motor. A small vertical feed force at the end of a lever carrying the cutting tool to lower the cutting tool to, and through, the workpiece.

The workpiece is held firmly in a vice provided on the upper platform and the combination of the rotation of the cutting tool and the vertical feed force causes the metal workpiece to be split or cut through.

2.2 Specifications and Design of Components

2.2.1 Selection of Abrasive Cutter

Jain (2008) recommended wheels bonded by the rubber process as suitable for fine parting off operation. An abrasive wheel, rubber bonded, 300 mm diameter and 4 mm thickness is selected for the design.

2.2.2 Specification of Cutting Parameters

2.2.3 Speed of Abrasive wheel (N)

Jain (2008) stated that the rubber bonded abrasive wheel of up to 0.1 mm thickness can be operated at speeds ranging from 3000 to 5000 m/min. Expressed in revolutions per minute, using,

$$N = \frac{60U}{\pi D}$$

Where, U = linear velocity at the circumference of the wheel, and

D = diameter of the abrasive cutter i.e. 300 mm
 The range of speed is thus 1591 to 2652 rpm. A speed of 2500 rpm is selected which corresponds to 39.3 m/s.

2.2.4 Feed Speed (f_v)

Nagpal (2005) and Jain (2008) noted that a typical value of feed ranges between 0.2 to 0.6 m/s. A feed speed of 0.6 m/s, which corresponds to 100 mm/min, is chosen.

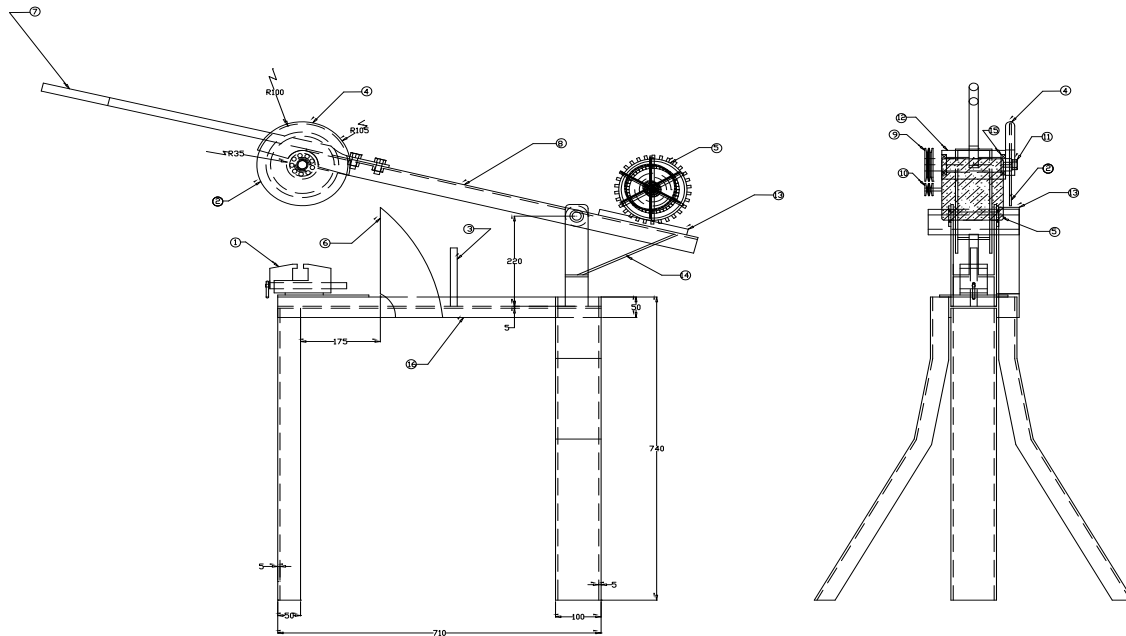


Figure 1: The High Speed Abrasive Cutting Machine



- 1-Machine vice; 2- Abrasive cutting disk; 3- Stopper; 4- Cutting disk guide; 5- Electric motor; 6- Grit collector; 7- Handle; 8- Lever arm; 9- Driven pulley; 10- Electric motor pulley; 11- Disk holder and bolt; 12- Spindle shaft housing; 13- Electric motor base; 14- Lever end stopper; 15- Bearings; 16- Machine base.

Plate 1: The high-speed abrasive cutting machine

2.2.5 Feed Rate (f)

This is the feed of the cutter in one revolution and is obtained using

$$f = \frac{f_v}{N}$$

But $f_v = 100$ mm/min; and $N = 2500$ rpm. Therefore,

$$f = \frac{100}{2500} = 0.04 \text{ mm/rev}$$

The feed rate is 0.04 mm/rev.

2.2.6 Depth of Cut (t)

This is the thickness of the layer removed in one pass in a direction perpendicular to the direction of feed motion (Nagpal, 2005). The feed is across the cross section of the workpiece. Hence, the depth of cut equals the thickness of the abrasive cutter.

$$t = 4 \text{ mm}$$

2.2.7 Width of Cut (W)

This is taken as the greatest width of the workpiece to be cut. A maximum width of 100 mm is selected for the design.

2.2.8 Volume of Material removed per Unit Time (V)

According to Singh, 2008 and Jain, 2008 this can be derived using

$$V = f_v t W$$

$$V = 100 \frac{\text{mm}}{\text{min}} \times 4 \text{ mm} \times 100 \text{ mm}$$

$$V = 40,000 \frac{\text{mm}^3}{\text{min}}$$

2.2.9 Power Required (P)

This is calculated, Nagpal, 2005; Jain, 2008 using

$$P = \frac{Ve}{60} \text{ Watts}$$

Where, e = specific energy of the material = 5.5 J/mm^3 for steel with BHN 400 (Singh, 2008)

Therefore,

$$P = \frac{40,000 \times 5.5}{60} W$$

$$P = 3666.67 W$$

The power required for cutting is 3.67 kW.

2.2.10 Total Tangential Cutting Force

This is evaluated by using (Jain, 2008; Singh, 2008)

$$F_T = \frac{60,000 \times P}{\pi D N}$$

$$F_T = \frac{60,000 \times 3666.67}{\pi \times 300 \times 2500}$$

$$F_T = 93.4 N$$

2.2.11 Radial Force (F_R)

This is the force perpendicular to the total tangential force (Jain, 2008) and is taken as the required feed force. It is evaluated, Singh, 2008, using

$$F_R = 2F_T$$

$$F_R = 2 \times 93.4 N$$

$$F_R = 186.8 N$$

2.2.12 Shaft Design

The abrasive cutting wheel, which is mounted on one end of a shaft which is driven by a pulley mounted on the other end. The shaft is thus assumed to be subjected to pure torsion.

The torsional moment, or torque, on the shaft is evaluated, according to Sharma and Aggarwal, 2006; Jain, 2004; Shigley and Mischke, 2003, using

$$T = \frac{60P}{2\pi N} Nm$$

$$T = \frac{60 \times 3666.67}{2\pi \times 2500} Nm$$

$$T = 14 Nm$$

According to Sharma and Aggarwal, 2006; Shigley and Mischke, 2003, the minimum shaft diameter is evaluated using

$$d = \left[\frac{16Tn}{\pi\tau} \right]^{\frac{1}{2}}$$

Where

n = factor of safety which is taken as 4.0 for known materials that are to be employed in uncertain environments or subjected to uncertain stresses and loads (Sharma and Aggarwal, 2006; Jain, 2004; Singh, 2008).

τ = the maximum allowable shear stress, taken as 55 MN/m² for commercial steel shafting (Sharma and Aggarwal, 2006).

Therefore,

$$d = \left[\frac{16 \times 14 \times 4}{\pi \times 55 \times 10^6} \right]^{\frac{1}{2}}$$

$$d = 0.017 \text{ m}$$

The minimum shaft diameter is 17 mm. However, a diameter of 30 mm is chosen.

Sharma and Aggarwal (2006) recommend that the torsional deflection of a shaft must be less than 0.25°/m (or 0.0044 rad/m) for machine tools. The torsional deflection of the shaft is determined using (Sharma and Aggarwal, 2006; Jain, 2004)

$$\theta = \frac{TL}{GJ} \text{ rad}$$

Where,

L = length of the shaft taken to be 190 mm

G = modulus of rigidity of steel in shear which is approximately 80 GN/m² (Singh, 2008; Sharma and Aggarwal, 2006)

J = Polar moment of inertia of cross-sectional area about the axis of rotation and is calculated using

$$J = \frac{\pi d^4}{32} = 8 \times 10^{-8} \text{ m}^4$$

Thus, the deflection per unit length is evaluated by

$$\frac{\theta}{L} = \frac{T}{GJ} \frac{\text{rad}}{\text{m}}$$

$$\frac{\theta}{L} = \frac{14}{80 \times 10^9 \times 8 \times 10^{-8}} \frac{\text{rad}}{\text{m}}$$

$$\frac{\theta}{L} = 0.0022 \frac{\text{rad}}{\text{m}}$$

The torsional deflection per unit length is 0.0022 rad/m which is less than the critical torsional deflection. For the length of shaft assumed, the total deflection is 0.00042 rad.

The housing of the shaft was considered as a loose running fit. It is made of a hollow cylinder with an outer diameter of 70 mm, and is recessed at both ends to allow for roller bearings.

2.2.13 Specification for Machine Frame and Upper Platform

The frame was constructed by using U-bars, flat bars and the upper platform was made of an I-section so as to provide the required rigidity and support for machining. The parts of the base were joined by electric arc welding. The height of the base was 740 mm.

2.3 Grinding/Wear Ratio

The life of an abrasive cut-off wheel is determined by the wheel wear and is expressed as (Sahu and Sagar, 2006)

$$G = \frac{V_{WP}}{V_{Wheel}}$$

Where, V_{WP} is the volume of work removed and V_{Wheel} is the volume of wheel removed. The grinding/wear ratio was evaluated for each cut.

3.0 EVALUATION OF THE HIGH SPEED ABRASIVE CUTTING MACHINE

The designed machine was built and tested using two cylindrical workpiece each made from mild steel and stainless steel which are common engineering materials used for production. A 5 hp (3.75kW) electric motor was mounted on the machine and two v-belts were used to transmit motion to the pulley which drives the abrasive cutter.

Rods with diameters of 25 mm and 60 mm, each of mild steel and stainless steel were clamped in the bench vice and cut with the abrasive cutting machine with the feed being applied manually. Three tests were conducted per sample. The time taken to cut each sample was recorded. Also, the reduction in the diameter of the abrasive wheel during each operation was noted and used to evaluate the rate of wear of the abrasive wheel. One of each rod sample was also cut using an automatically operated power hack saw.

4.0 RESULTS AND DISCUSSIONS

The results of the test obtained from cutting mild steel rod samples of 25mm diameter with

the high speed abrasive cutter are presented in table 1. While table 2 presents the results of the test obtained from cutting mild steel rod samples of 60mm diameter using the high speed abrasive cutter. Tables 3 and 4 present results for test carried out when the high speed abrasive cutter is used to cut stainless steel rod samples of 25mm diameter and 60mm diameter respectively. Table 5 compares the average time taken when the high speed abrasive cutter was used with the time taken when the power hacksaw was used to cut the same samples of stainless steel and mild steel rods.

Table 1: Results obtained from cutting 25mm mild steel rod samples using the high speed abrasive cutter

Test no.	Time of cut (sec)	Reduction	Grinding/Wear ratio
		in cutting disc diameter (mm)	
1	7.0	0.80	1.30
2	8.0	0.70	1.49
3	7.5	0.85	1.23
Average	7.5	0.78	1.34

Table 2: Results obtained from cutting 60mm mild steel rod samples using the high speed abrasive cutter

Test no.	Time of cut (sec)	Reduction	Grinding/Wear Ratio
		in cutting disc diameter (mm)	
1	25.0	1.90	3.17
2	20.0	2.00	3.01
3	19.0	1.90	3.17
Average	21.3	1.93	3.12

It was observed, as presented in table 1, that the average time taken when the abrasive cutter was used to cut the mild steel rod samples with diameter of 25mm was 7.5

seconds while rod samples of the same material but with diameter of 60mm was cut in 21.3 seconds as shown in table 2. However, the average time taken to cut stainless steel rod samples with diameter of 25mm was 15 seconds as shown in table 3 while it was observed, as shown in table 4, that samples of stainless steel with diameter of 60mm took about 136.7 seconds to be cut off with the high speed abrasive cutter.

Table 3: Results obtained from cutting 25mm stainless steel rod samples using the high speed abrasive cutter

Test no.	Time of cut (sec)	Reduction	Grinding/Wear Ratio
		in cutting disc diameter (mm)	
1	15.0	1.30	0.80
2	17.0	1.50	0.70
3	14.0	1.20	0.87
Average	15.3	1.30	0.79

Table 4: Results obtained from cutting 60mm stainless steel rod samples using the high speed abrasive cutter

Test no.	Time of cut (sec)	Reduction	Grinding/Wear Ratio
		in cutting disc diameter (mm)	
1	120	3.00	2.01
2	140	3.50	1.72
3	150	3.30	1.83
Average	136.7	3.30	1.85

Table 5: Comparison of results obtained from using the high speed abrasive cutter with the power hacksaw.

Sample	Diameter (mm)	Time of cut (sec)	
		High speed abrasive cutter	Power hacksaw
Mild Steel	25	7.5	19.8
	60	21.3	59.4
Stainless steel	25	15.3	41.2
	60	136.7	550.0

Table 5 compares the operation of the power hacksaw when used to cut similar samples as those cut by the high speed abrasive cutter. It was observed that stainless steel took more time to be cut than mild steel. It was also noticed that the high speed abrasive cutter cut at a faster rate. The cutting process was also found to be easier with the high speed abrasive cutter than the power hacksaw. The high speed abrasive cutter also gave a better finish than the power hacksaw.

There was a reduction in the cutting wheel diameter with every cut. It was noticed that when the wheel was used to cut stainless steel, the abrasive wheel had a greater wear than when it was used to cut

5.0 CONCLUSION

The high speed abrasive cutter designed has a better efficiency than the conventional cut-off operations involving the use of power hacksaws. The rate of wear of the abrasive wheel depends on the hardness of the material being cut which depends on its composition. The high speed abrasive cutting machine can be used as a cut-off machine in workshops and can be fabricated in a machine shop which is

mild steel. Stainless steel commonly has a composition of about 12% to 20% chromium and 8% to 10.5% nickel. This makes stainless steel as an alloy to be stronger, harder and tougher than mild steel (DOE, 2001). Thus, it can be deduced that the hardness of the stainless steel caused it to take more time to be cut and also to cause a greater wear of the abrasive wheel.

The wear of the abrasive wheel is comparable to the observation of Sarwar et al. (1996) which noted that nickel based alloys, which include stainless steel, caused a rapid rate of wear of the circular saw blade. However, the abrasive wheel is more suitable than the high speed steel circular saw blade because it gives a better surface finish, produces minimal heat and there is no plastic deformation of the tool caused by localized temperatures.

The cut-off operation of the high speed abrasive cutting machine was slower than abrasive cut-off machines designed by Everett (2007). Everett (2007) designed a 14 inch abrasive cut-off which runs on a 10 hp (7.5kW) motor and is capable of cutting a 50mm cold rolled solid in 7 seconds, and a 20 inch abrasive cutter which cuts 75mm cold rolled steel in 21 seconds and 50mm stainless steel in 8 seconds.

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