HSE information sheet

CNC turning machines: Controlling risks from ejected parts

Engineering Information Sheet No 33

Introduction

This guidance aims to help machine users carry out an assessment of the risks from accidental ejection at CNC turning machines and confirm that the risk control measures are effective. Because of the variables involved it is difficult to make a precise assessment. The following guidance is intended to provide a 'best estimate' upon which judgements about risk can be made. The guidance is mainly concerned with guard strength but other means to minimise risks from ejection are also considered.

Recent research has shown that polycarbonate materials used in CNC turning-machine vision panels can degrade after exposure to the metalworking fluids and lubricants used in the machining process. This can result in a significant reduction in the impact resistance of the material and may be as much as 10% per year in a typical manufacturing machine-shop environment, as shown in Figure 1[1] below. **(NB: Table 2, not the data contained in the figure, should be used as a basis for determining the residual impact resistance of vision panels.)** There are significant safety implications because of the potential for high-energy ejections at turning machines. Operators may be at risk of injury because, in time, vision panels may not be able to contain ejected parts.

Legal requirements

The Provision and Use of Work Equipment Regulations 1998[2] require that risks from ejection are controlled by 'engineering' means where it is reasonably practicable to do so (regulation 12) and that these safeguards are properly maintained (regulation 5). The requirements for equipment suitability (regulation 4) and appropriate information, training, instruction and supervision are also relevant.

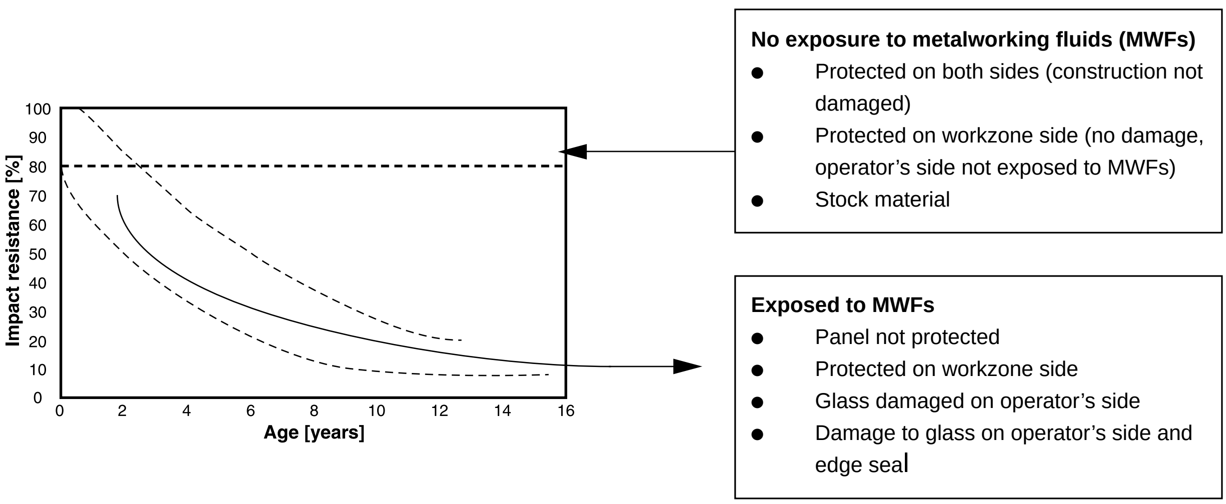
Ejection

Most ejections at CNC turning machines are caused as a result of operator/setter error and failure to properly maintain work-holding devices. The likelihood of ejection can vary considerably depending upon the type of work being done. Work involving faceplates and other turning fixtures need special care in operation while bar-fed machines, using collets for small components, are less hazardous.

To determine if the machine guard will be strong enough to contain ejected parts the first step is to identify which part(s) could foreseeably be ejected due to its rotation and off-centre location. Particular attention should be given to chuck jaw assemblies, workpiece clamps, faceplate balance weights and component parts of turning fixtures. The potential for over-speed conditions, collisions and other kinds of reasonably foreseeable 'errors' should be considered. The circumstances of previous ejection incidents should also be considered, whether or not any injuries were caused. The existing and intended applications of the machine should be assessed. Other factors making ejection likely include:

(a) rotational speed for the particular application;
(b) weight and type of gripping jaws if non-standard;
(c) radius at which gripping jaws/clamping devices are operating;
(d) gripping force applied to the workpiece (static/dynamic conditions);

Figure 1 Ageing of polycarbonate vision panels



(e) whether the workpiece is gripped externally or internally;
(f) condition of chuck/fixture, eg inadequate lubrication/maintenance;
(g) state of balance;
(h) magnitude of the cutting forces involved (depth, feed rate and workpiece overhang).

The ‘worst case’ situations should be identified based on an estimate of the weight of the part, its radius from the spindle centreline and its speed. (Remember when estimating that doubling the weight doubles the energy but doubling either the speed (rpm) or the ejection radius increases energy by a factor of four, ie smaller parts may represent a greater hazard). Any situation where the ‘ejected part’ would be directly in line with the vision panel should be investigated. On some machines the chuck area may be ‘protected’ by a steel portion of the guard, but a new chuck or modified work-holding arrangement may change this situation. More accurate measurements should be taken for these worst case situations. The approximate ejection energy of the parts can then be determined using Table 1[3] against the following values:

(a) weight of the part in kilos;
(b) ‘ejection radius’ (point of release radius): Generally the centre of gravity position of the item relative to the spindle centreline will constitute the release radius but for chuck jaw assemblies, as the release radius is outside the chuck body periphery, a factor of 1.25 of the chuck diameter should be applied;
(c) maximum rotational speed: Consider the possible failure to limit maximum rpm on machines with constant surface speed (CSS).

Using the above values read off the corresponding ejection energy (kJ). Where a particular weight, radius or rpm is not given in Table 1 use the nearest higher values to obtain an estimate. Record the results obtained. A worked example is given below.

Engineering controls

The next step will be to determine the suitability of the existing guard design and the materials used in its construction to contain the anticipated maximum ejection energy. (It should be noted that machine guards are not designed to contain ejections in all circumstances. New machines constructed to European Standards[4] normally apply values based on the strength needed to contain an ejected chuck jaw rotating at the maximum spindle speed.)

Materials

The materials used for the guard and vision panel should be identified. The vision panel is likely to be polycarbonate (a clear ductile plastic when new), glass, or a combined lamination of glass and polycarbonate. The thickness of the guard and vision panel material will need to be measured.

Glass: Single sheets of glass will generally be 4-6 mm thick and, even if toughened, will be of inadequate strength to resist a high-energy ejection impact.

Polycarbonate will be recognisable as a plastic material ranging from 4 to 20 mm in thickness. Deep scratches or discoloration will indicate a deteriorated condition and any cracked or damaged material is unsuitable for continued use.

Laminated constructions may be of two-layer glass/polycarbonate or three-layer glass/polycarbonate/glass or polycarbonate. Overall laminate thickness will range from 8 to 30 mm. Only the polycarbonate layer provides impact resistance. The two-layer units will suffer from degradation in the same way as single unprotected sheets of polycarbonate. However, the three-layer units can be considered to have retained their original strength so long as metal-cutting fluid has not entered the assembly and the

Table 1: Ejection energy (kJ)

Ejected weight	Ejection radius	At maximum spindle revolutions per minute of 1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
		kJ	kJ	kJ	kJ	kJ	kJ	kJ	kJ	kJ	kJ	kJ
	400 mm	0.878	1.974	3.510								
	350 mm	0.672	1.511	2.687	4.199			Beyond viable range				
	300 mm	0.494	1.110	1.974	3.085	4.442						
	250 mm	0.343	0.771	1.371	2.142	3.085	4.199					
	200 mm	0.219	0.494	0.878	1.371	1.974	2.687	3.510	4.333			
1.0 kg	175 mm	0.168	0.378	0.672	1.050	1.512	2.058	2.687	3.317	4.199		
	150 mm	0.123	0.278	0.494	0.772	1.112	1.514	1.974	2.437	3.085	3.733	4.442
	125 mm	0.086	0.193	0.343	0.535	0.771	1.049	1.371	1.693	2.142	2.592	3.085
	100 mm	0.055	0.123	0.219	0.343	0.494	0.672	0.878	1.084	1.371	1.659	1.974
	75 mm	0.031	0.070	0.124	0.193	0.278	0.378	0.494	0.610	0.771	0.934	1.111
	63 mm	0.022	0.049	0.087	0.136	0.196	0.267	0.348	0.430	0.544	0.659	0.784
	50 mm	0.014	0.031	0.055	0.086	0.124	0.169	0.220	0.272	0.343	0.415	0.494
	38 mm	0.008	0.018	0.032	0.050	0.071	0.097	0.127	0.157	0.198	0.239	0.285

protective layers are not cracked. Damage of this kind makes the vision panel unsuitable for continued use. The impact resistance of three-layer panels with an overall thickness of less than 12 mm should be based on no more than 4 mm of polycarbonate unless confirmed otherwise by the manufacturer.

Steel: The guard and its supporting parts will generally be made of steel. Where a punched steel sheet or steel bars have been provided to supplement the vision panel, assess the spacing to determine if they will be able to contain all the sizes of ejection items identified.

Guard and vision panel fixings

The method of fixing the vision panel into the guard needs to be examined and assessed for its strength. A robust mechanical connection is needed to prevent a high-energy impact from separating the vision panel from the guard. Moulded rubber location arrangements have proved to be inadequate for this. There should be at least a 20 mm overlap of the vision panel all around the inside of the guard aperture. Clamping is the preferred method of retaining the vision panel in position rather than bolting through the vision panel material.

Material impact resistance

Provided the condition of the vision panel and its fixing to the guard are considered adequate, the next step is to determine the age of the polycarbonate. In assessing this it must be assumed that it is the original material/vision panel fitted to the machine, unless there is definite evidence of the date when the vision panel was replaced. (If the vision panel is changed it is recommended that a record is kept in the maintenance log or on a tag/sticker on the machine.)

For vision panels which are not fully protected determine the residual impact resistance for the polycarbonate from Table 2[3] (see the worked example below). The value for the vision panel needs to be greater than the highest foreseeable ejection energy established from Table 1. The thickness of the steel guard in the ejection zone needs to be approximately one third of the required thickness of polycarbonate. If the steel guard is too thin or the vision panel strength values are below the foreseeable ejection energy it will be necessary to take remedial action.

Worked example

Assume that a machine is three years old and has a maximum spindle speed of 3300 rpm. It has a vision panel made of 8 mm thick polycarbonate with toughened glass on the inside but no other protection on its outer surface.

The machine has a 180 mm diameter chuck and the maximum chuck jaw weight has been determined as 1.8 kg. If a chuck jaw was released its centre of gravity would be some 30 mm outside the chuck body. The release radius would therefore be half the chuck diameter plus the 30 mm, making a total of 110 mm. This gives sufficient information to proceed.

Using the tables

Table 1 is used to initially find the ejection energy for a 1 kg weight. The nearest higher release radius is 125 mm and the nearest higher maximum rotational speed is 3500 rpm. For these conditions the energy value is 1.049 kJ. Multiply this value by the actual weight of the chuck jaw. This gives an energy value of 1.882 kJ or rounded 1.9 kJ. Now go to Table 2.

In Table 2 the mass of the jaw assembly lies between the 1.25 kg and the 2.5 kg sections. In this case the data in the 1.25 kg section should be used. This is because the values in this section are calculated taking into account a smaller impact area for the ejected part. Smaller impact areas have a greater penetrating effect and this is compensated for by a slightly increased thickness of polycarbonate. Reading across from the 1.9 kJ energy level for new polycarbonate a 6 mm thickness is required.

The machine is, however, fitted with 8 mm polycarbonate that is three years old and has been subject to deterioration. Read across from the 8 mm polycarbonate thickness row, in the 1.25 kg section, to the 3 yrs column. This indicates that the material now has an impact resistance of only 1.8 kJ. This is below the 1.9 kJ required to contain the chuck jaw. For continued use some remedial action is required.

Remedial measures

In cases where the control measures are found to be deficient, further information should be sought from the manufacturer or supplier, wherever possible. The manufacturer should be able to provide information about design details of guards, the availability of guard upgrades, other recommended modifications and sources of suitable materials. The future maintenance requirements should also be considered as part of the assessment. In cases where long-term control measures are not going to be adopted and the circumstances of use will not change significantly this may include specifying periodic exchange intervals for vision panels.

In the example above there are a number of measures that could be taken:

(a) The CNC part-programmes could be amended to use a maximum spindle speed of 3000 rpm. This would extend the safe use of the machine for about a year but the polycarbonate would continue to deteriorate. (The maximum speed would need to be verified before start-up on a new part-programme.);

Table 2: Thickness of polycarbonate (mm) and residual impact resistance over time (years)

Ejected weight	Polycarbonate thickness	Age of polycarbonate (years)								
		New	1 yr	2 yrs	3 yrs	4 yrs	5 yrs	6 yrs	7 yrs	8 yrs
	mm	kJ	kJ	kJ	kJ	kJ	kJ	kJ	kJ	kJ
5.0 kg Having impact area of 1156 mm^2	40	23.1	20.8	18.5	16.2	13.9	11.6	9.2	6.9	4.6
	30	17.3	15.6	13.9	12.1	10.4	8.7	6.9	5.2	3.5
	25	14.5	13.0	11.6	10.1	8.7	7.2	5.8	4.3	2.9
	21	12.1	10.9	9.7	8.5	7.3	6.1	4.8	3.6	2.4
	18	10.4	9.4	8.3	7.3	6.2	5.2	4.2	3.1	2.1
	15	8.7	7.8	6.9	6.1	5.2	4.3	3.5	2.6	1.7
	12	6.9	6.2	5.5	4.9	4.2	3.5	2.8	2.1	1.4
	10	5.8	5.2	4.6	4.0	3.5	2.9	2.3	1.7	1.2
	8	4.6	4.2	3.7	3.2	2.8	2.3	1.8	1.4	0.9
	6	3.5	3.1	2.8	2.4	2.1	1.7	1.4	1.0	0.7
	4	2.3	2.1	1.8	1.6	1.4	1.2	0.9	0.7	0.5
2.5 kg Having impact area of 900 mm^2	25	11.3	10.1	9.0	7.9	6.8	5.6	4.5	3.4	2.3
	21	9.5	8.5	7.6	6.6	5.7	4.7	3.8	2.8	1.9
	18	8.1	4.1	6.5	5.7	4.9	4.1	3.2	2.4	1.6
	15	6.8	6.1	5.4	4.7	4.1	3.4	2.7	2.0	1.4
	12	5.4	4.9	4.3	3.8	3.2	2.7	2.2	1.6	1.1
	10	4.5	4.1	3.6	3.2	2.7	2.3	1.8	1.4	0.9
	8	3.6	3.2	2.9	2.5	2.2	1.8	1.4	1.1	0.7
	6	2.7	2.4	2.2	1.9	1.6	1.4	1.1	0.8	0.5
	4	1.8	1.6	1.4	1.3	1.1	0.9	0.7	0.5	0.4
1.25 kg Having impact area of 625 mm^2	21	6.6	5.9	5.3	4.6	3.9	3.3	2.6	2.0	1.3
	18	5.6	5.1	4.5	3.9	3.4	2.8	2.3	1.7	1.1
	15	4.7	4.2	3.8	3.3	2.8	2.3	1.9	1.4	0.9
	12	3.8	3.4	3.0	2.6	2.3	1.9	1.5	1.1	0.8
	10	3.2	2.8	2.5	2.2	1.9	1.6	1.3	0.9	0.6
	8	2.5	2.3	2.0	1.8	1.5	1.3	1.0	0.8	0.5
	6	1.9	1.7	1.5	1.3	1.1	0.9	0.8	0.6	0.4
	4	1.3	1.1	1.0	0.9	0.8	0.6	0.5	0.4	0.3
1.0 kg Having impact area of 506 mm^2	18	4.6	4.1	3.6	3.2	2.7	2.3	1.8	1.4	0.9
	15	3.8	3.4	3.0	2.7	2.3	1.9	1.5	1.1	0.8
	12	3.0	2.7	2.4	2.1	1.8	1.5	1.2	0.9	0.6
	10	2.5	2.3	2.0	1.8	1.5	1.3	1.0	0.8	0.5
	8	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4
	6	1.5	1.4	1.2	1.1	0.9	0.8	0.6	0.5	0.3
	4	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2
0.625 kg Having impact area of 361 mm^2	18	3.2	2.9	2.6	2.3	1.9	1.6	1.3	1.0	0.6
	15	2.7	2.4	2.2	1.9	1.6	1.4	1.1	0.8	0.5
	12	2.2	2.0	1.7	1.5	1.3	1.1	0.9	0.6	0.4
	10	1.8	1.6	1.4	1.3	1.1	0.9	0.7	0.5	0.4
	8	1.4	1.3	1.2	1.0	0.9	0.7	0.6	0.4	0.3
	6	1.1	1.0	0.9	0.8	0.6	0.5	0.4	0.3	0.2
	4	0.7	0.6	0.6	0.5	0.4	0.4	0.3	0.2	0.1

(b) The polycarbonate could be replaced with new 8 mm unprotected material and then changed periodically;
(c) The vision panel could be replaced with a completely sealed laminated assembly using a centre sheet of 6 mm new polycarbonate. (**Important note: machine users should never attempt to 'manufacture' their own laminated vision panels as these are specially made units which require specific bonding methods, adhesives and sealing materials. Only units supplied or recommended by the machine manufacturer should be used**);
(d) A steel protection plate, properly supported and securely bolted to the guard, could be added over the vulnerable area of the vision panel. The thickness of steel would need to be approximately one third of the thickness of new polycarbonate required for the 1.9 kJ energy value.

(Note: Only a new fully laminated and **sealed** vision panel or the protective steel plate solutions can be considered as long-term solutions.)

The following additional measures should also be considered, especially in cases where the manufacturer/agent no longer exists or technical data cannot be obtained:

(a) If possible reduce the mass (weight) of items which may be ejected;
(b) Improve the design/security of work-holding devices;
(c) Replace any defective/worn chucks and improve maintenance;
(d) Move 'high-risk' work to a 'safer' machine.

Safe working practices

In addition to improvements in guard strength the likelihood of ejection can be reduced by adopting good working practices and ensuring that equipment, particularly work-holding devices (eg chucks and fixtures), are properly maintained. Detailed information concerning the safe use of chucks should be available from the machine manufacturer or chuck supplier. Proper training of operators and machine setters is important to ensure that the correct machining parameters are selected and that programming errors are minimised.

This guidance is not intended to apply to other types of machine tool as the data have been derived from work done specifically on turning machines.

Further information

This information sheet was prepared in conjunction with:

Machine Tool Technologies Association (MTTA)

Engineering Employers Federation (EEF)

British Turned Parts Manufacturers Association (BTMA)

References

1 Source of data in figure: D Mewes et al Strength of materials when subjected to impact stresses BIA Institut, St Augustin, Germany.

2 Safe use of work equipment. Provision and Use of Work Equipment Regulations 1998. Approved Code of Practice and guidance L22 HSE Books 1998 ISBN 0 7176 1626 6

3 The data contained in Tables 1 and 2 are derived from formulae in BS EN 12415 : 2000

4 BS EN 12415:2000 Machine tools. Safety. Small numerically controlled turning machines and turning centres

Further reading

Health and safety in engineering workshops HSG129 1999 HSE Books ISBN 0 7176 1717 3

While every effort has been made to ensure the accuracy of the references listed in this publication, their future availability cannot be guaranteed.

Further information

HSE priced and free publications are available by mail order from HSE Books, PO Box 1999, Sudbury, Suffolk CO10 2WA. Tel: 01787 881165 Fax: 01787 313995 Website: www.hsebooks.co.uk (HSE priced publications are also available from bookshops.)

For information about health and safety ring HSE's InfoLine Tel: 08701 545500, Fax: 02920 859260, e-mail: hseinformationservices@natbrit.com or write to HSE Information Services, Caerphilly Business Park, Caerphilly CF83 3GG. You can also visit HSE's website: www.hse.gov.uk

British Standards are available from BSI Customer Services, 389 Chiswick High Road, London W4 4AL. Tel: 020 8996 9001 Fax: 020 8996 7001
Website: www.bsi-global.com

This leaflet contains notes on good practice which are not compulsory but which you may find helpful in considering what you need to do.

Printed and published by the Health and Safety Executive 05/01 EIS33 C150