The Reconditioning of War-Damaged Machine Tools

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At the time when damage to factories by enemy bombing was most severe, circumstances necessitated the recovery of all possible plant as soon as practicable without regard to cost. Hence many very severely damaged machines had to be dealt with, and the problems raised were drastic.

Gutteridge, in a paper read before the Institution in February 1942,* discussing the liability of damage of mechanical plant, gave five types of damage; an analysis, on these lines, of 205 machines that were dealt with, is given in Table 1.

Table 1. Analysis of War Damage to Machine Tools

Damaged by direct hit from high-explosive bomb	Nil
„ „ blast	18
„ „ fire	166
„ „ falling debris	56
„ beyond repair	22
„ by water and exposure	182
Total number of machines examined	205

Three important deductions could be drawn from this table:—

(*a*) Damage by direct hit was so severe that the machine was not worth repair.

(*b*) Fire was a very potent cause of damage.

(*c*) Water, whether used as a means of fire attack or resulting from simple exposure to the weather in a wrecked building, was most destructive.

The effects of blast, as illustrated by the appearance of the small milling machine shown in Fig. 1, Plate 1, were usually very severe. Extensive fractures of main cast iron parts, and excessive distortion of shafts and screws were characteristic features of this type of damage; whilst fire caused serious cracks or distortion. Fire damage was the most difficult to remedy. Whitemetal, and in severe cases bronze, bearings were melted. Typical examples are shown in Figs. 2 and 3, Plate 1.

A marked similarity in the position and extent of cracking was found in similar machines, emphasizing the known fact that considerable casting stress existed in complicated main body castings of machine tools. This showed the desirability of a stress-relieving process after rough machining; the author was meeting this situation in his production of new machine tools by annealing lathe beds at 450 deg. C. (842 deg. F.) for 3 hours; the resultant Brinell hardness numbers on lathe beds averaged 187, after treatment.

Damage due to falling debris and the falling of the machine due to collapse of floors, produced results such as those illustrated in Fig. 4, Plate 1. Little abnormality appeared in this, although the damage was usually severe.

Two effects were evident in the case of damage by water. Where parts had attained high temperature in the fire, black oxide scale was formed on steel parts, otherwise the effect was one of normal rusting. There was a probability that some cracking of cast iron framing was due to sudden quenching from high temperature; water damage was generally the most extensive.

Electrical plant suffered severely by fire, and in a lesser degree by water. Motor windings were completely destroyed, the copper of the windings being partially melted in some cases, thus necessitating the entire rewinding of motors and complete replacement of switch gear and wiring; prolonged exposure of undamaged electrical equipment to moisture also levied its toll.

It will be realized from the preceding account that when, after removing debris, it was possible to commence dismantling, difficulty was experienced with tight threads, bent shafts, partially melted bushes which locked shafts in place, and softened heads of "Allen" screws. The general method was to dismantle a machine in major units, using penetrating oil or paraffin, soaking for 24 hours to ease tight threads. In some cases bolt heads were cut off, and bent shafts were cut into pieces. The major units when severed were then immersed completely in tanks containing a mixture of paraffin and a very light spindle oil or containing a strong solution of soluble oil in water—preferably heated. After 24 hours of soaking, further dismantling was managed without much trouble. Considerable use was made of photographs of major units before dismantling to serve as a record on reassembly.

" Allen" screws frequently caused difficulty as the softened heads sheared in the hexagon fit, and the only resort was to drill out the whole screw. This was a slow process, as the body of the screw remained hard in many cases. Castings were all cleaned by shot-blasting, and then given one coat of primary grey paint; shafts and spindles that were fit for re-use were chemically cleaned of rust by muriatic acid pickle, then scratch-buffed and polished. Ball races were cleaned by immersion in petrol, and were then regreased; headstock gears were shot-blasted to remove carbonized oil, the splined bores being protected by wood covers. The major work undertaken in the rebuilding process was that of repairing the broken, cracked, and warped main body castings by welding, and this operation on cast iron was a complicated metallurgical operation. In the process of welding, the composition of the filler rod or electrode was changed, silicon and manganese being reduced and combined carbon increased giving hard metal in the weld. Compensation for this effect was partially obtained by increasing the silicon and manganese of the rod above that of the casting. A hard ring was found in the parent metal around the weld, and the operation of welding however carefully conducted produced cooling stresses. Heating prior to welding with slow cooling after was desirable to reduce these difficulties. By reason of the important metallurgical aspect of the welding operation, this work was all done in the iron foundry under the control of the foundry supervisor.

Three methods were used:—

(1) Gas welding with cast iron filler rod containing at least 3·0 per cent silicon, castings being preheated and cooled slowly. This was the best method for wearing surfaces and was used unless the bulk of the casting prevented satisfactory preheating and cooling; these operations required great care on large complicated main body castings.

(2) Electric welding with covered electrodes of proprietary brands suitable for cast iron; such welds tended to be unmachinable, and a wearing face was difficult to scrape up to a fit.

(3) Bronze welding by arc, using proprietary brands of covered electrodes. This gave a strong and satisfactory weld for structural parts of the machine with less heat stress, and was used for all welds not crossing a wearing face.

These methods were used to deal with a fractured milling machine column, for which an iron patch was cast by ramming up the cavity of the column with sand, to the inside contour of

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* Proceedings, 1942, vol. 147, p. 99; vol. 148, p. 120, "Proneness to Damage of Plant through Enemy Action".

the column. A plaster of Paris model was then cast in place. This was bevelled at the edges, varnished, and used as a pattern for the cast patch which had steel studs cast in place along the bevelled edges for the weld, while the fractured edges of the column were also bevelled and studded. Fig. 5, Plate 2, shows the patch in place, preparatory to welding. The welding was carried out by gas, using high-silicon cast iron filler rod.

The "V" of the vertical face of the knee slide was welded in the same way. All this work was preheated and annealed after welding. As an alternative, patches cut from mild steel plate could be used instead of castings.

A much larger and more difficult problem was presented by the extensive cracking of a hydraulic cylindrical grinder body casting (one of four). Marked similarity in position and extent of cracking was found in these four bodies. Welding was carried out with bronze rod, and the welds cross-stitched to give added strength; the first run in the bottom of the V was made with a No. 10 covered electrode of iron, followed by a covering weld of No. 10 bronze electrode. Fig. 6, Plate 2, shows the finished operation, for which data are given in Table 2.

TABLE 2. REPAIR REQUIREMENTS FOR CRACKED CASTING

Shot blast	3 man-hours.
Chip, drill, and tap	80 man-hours, and 8 feet of $\frac{5}{16}$-inch copper rod for studs.
Weld	51 man-hours.
Weld material	133 No. 10 covered steel electrodes. 196 No. 10 bronze rods. 8 nickel-copper rods.
Total length of weld	330 inches.

All self-contained cutting-lubricant tanks in beds and trays were tested for watertightness after welding. The correction of the distortion of the body of the cylindrical grinding machine shown previously in Fig. 3, Plate 1, was carried out by fusion gas welding, using electrodes of cast iron containing at least 3 per cent silicon. The casting was preheated, the necessary material built up at the way end, and a new cast piece welded in the front panel of the body after cutting out the bulged portion. Fig. 7, Plate 2, shows the body when welded. The deposited cast iron on the slide ways showed a Brinell hardness number of 165 after machining.

A further example of the methods used for dealing with distortion is illustrated by the milling machine column shown in Fig. 8, Plate 2. In this case the distorted foot was chain-drilled and broken off, the fractured body and foot piece bevelled and prepared for welding, and then arc-welded with iron and brass electrodes as previously described. To accommodate the bend in the slideways, extra metal was gas-welded on them; and in machining, the width over the V's was reduced and allowed for in the assembly of the machine by fitting false strips to the fast side of the knee slide.

Beds, saddles, knee slides, tables, etc., were in all cases replaned on bearing surfaces, and in the absence of modern slide-way grinding equipment, were scraped to a bedding fit by the usual methods. The consequent interference with shaft and gearing centres on milling machine knee slides was compensated by false strips; capstan heads were bored in place from the machine spindle and bushed back to standard. No cases of flame-hardened beds were dealt with. Experience showed that beds which had suffered severe heating and cracking and then been reclaimed by the preceding methods were in a good condition for stability and as good as properly aged castings in this respect.

Spindles were found slightly bent in many cases and were not straightened but replaced. Casehardened spindles were replaced if they showed tempering colour, but as heat-treated spindles in general had not attained such temperatures as to interfere with the heat treatment as checked by Brinell reading, they were reground and fitted to new bushes. In the case of single-spindle automatics, complicated spindle and collar parts of hardened steel were reclaimed by hard chrome plating.

Headstock gears of heat-treated steel were checked by Brinell and seldom required replacement, but casehardened and ground gears had to be replaced by new gears when showing tempering colour. In the earlier stages of this work, ball and roller bearings were replaced if they showed temper colour, but shortage of supplies led to the practice, on instruction from the Machine Tool Control section of the Ministry of Supply, of using any race that still retained a Rockwell hardness in excess of C.50. The author had no experience or information as to the behaviour of such partially softened races in practice; they were probably satisfactory for hand motions, but their suitability for main spindle drive would appear to have been doubtful. An organization had by now been brought into existence for repairing defective ball and roller bearings, presumably by rehardening and grinding the races, and fitting special sized balls and rollers. Thrust races were repaired in the factory by rehardening and grinding the races and fitting new balls and new cages where required, equipment for this work having been made previously for other armament work. Bronze bearings and bushes were replaced in phosphor bronze containing 10 per cent of tin.

Traverse screws requiring replacement were screw-milled and then finish-cut in the lathe to mating nuts previously cut in the same lathe, and the same practice was followed with centre lathe lead screws which were replaced if at all distorted. The work of replacing parts of the varied range of machines repaired without calling on makers (who in many cases could not help

TABLE 3. TEST OF VERTICAL MILLING MACHINE (MAKE, CINCINATTI NO. 3)

Test to be applied	Tolerance	Test
Levelling		
Table:—		
(1) Flat and level longitudinally	±0·0005 inch per foot	0·00025 inch
(2) Flat and level transversely	±0·0005 inch per foot	0·00025 inch
Alignment		
Spindle:—		
(3) Axial slip or float	0·0005 inch	0·001 inch
(4) External diameter true	0·00075 inch	0·0005 inch
(5) Internal taper true and size to gauge	0·001 inch maximum eccentric error	0·001 inch
Table:—		
(6) Flat and level traversing: longitudinally	0·0015 inch up to 24 inches movement; 0·002 inch up to 40 inches movement; 0·0025 inch over 40 inches movement. Clock reading over their respective lengths	0·0005 inch per foot
(7) Flat and level traversing: transversely	0·001 inch per foot	0·00075 inch per foot
(8) Table surface square with spindle: longitudinally	0·001 inch per foot	0·0005 inch per foot
(9) Table surface square with spindle: transversely	0·001 inch per foot	0·001 inch per foot
(10) Centre T-slot parallel with table movement: longitudinally	0·001 inch per foot,	0·001 inch per foot
(11) Centre T-slot square with transverse table movement	0·001 inch per foot	0·001 inch per foot
(12) Column ways for knee square with table: front to rear	0·001 inch per foot	0·001 inch per foot
(13) Column ways for knee square with spindle: side inclination	0·001 inch per foot	0·002 inch per foot
Spindle head:—		
(14) Hand-feed square with table: front to rear	0·001 inch per foot	0·00075 inch per foot
(15) Hand-feed square with table: longitudinally	0·001 inch per foot	0·001 inch per foot

due to pressure of new work, or who, in the case of American machines, were not quickly and easily accessible for replacement parts or blue prints) led to a very considerable amount of detail drawing work, and in the case of some older machines which had gone out of production, to actual redesign.

Dimensions were recorded in sketch books by apprentices taking turns at this duty and using the old parts as samples. Parts which were found to be missing entirely were copied from duplicate machines in the factory plant or at other neighbouring establishments, the managements of which were of the greatest assistance in allowing their machines to be dismantled for the purpose of measuring up detail parts, and in lending operators' handbooks for some of the more highly specialized machines.

Re-erection was carried out by customary methods of machine tool practice; and accuracy to the standard alignment charts issued jointly by the Institution of Mechanical Engineers and the Institution of Production Engineers was attempted. The typical tool chart for a vertical milling machine given in Table 3 shows that this standard was very nearly attained.

In all cases machines were run under power, and working tests were carried out where possible; in a few examples the tooling was completed and machine sent out ready for production of a definite component. Opportunity was taken in the case of older machines to improve lubrication methods; for instance, no open oilholes were left, lubricators were fitted in all instances, and wiping pads of felt were fitted to all slideways.

Comment has already been made on the extensive damage suffered by electrical equipment. Care was taken, before dismantling a machine, to trace all remains of the electrical connexions and to prepare a wiring diagram; in this direction much assistance was obtained from operators' handbooks. Motors were rewound locally, and American 60-cycle motors were changed to 50 cycles per second in the process, change in shaft speed being compensated for by new "tex-rope" pulleys or driving gears. Built-in switchgear, particularly of American origin was irreplaceable; in some isolated cases it was possible to rebuild it locally, but the principal method of replacement was to use domestic units separately mounted. Opportunity was taken to fit self-contained motor drive to older machines, previously countershaft-driven.

Paint finish consisted of one coat of prime grey after cleaning, followed after conclusion of tests with one coat of oil-proof grey; inside surfaces of gearboxes containing oil were coated with oil-resisting enamel before assembling was commenced.

This reclamation work was first started in January 1941, and over 200 war-damaged machines were dealt with. Since that date the organization built up has been used for reconditioning work both for the Machine Tool Control (Ministry of Supply) and for the factory; by May 1943, 578 of such reconditionings had been carried out and there were 160 machines in process at the time. By allocating different classes of machines to special groups of men, e.g. milling machines to one gang, centre lathes to another, etc., the men concerned rapidly gained proficiency in their work.

The rebuilding of the damaged machines was not a cheap process, but it was very necessary at the time, and it served the purpose of training a staff to machine tool work, none of whom had previously handled a scraper, surface plate, or dial indicator. This staff is now building new lathes and internal grinders with hydraulic table motion, and was also freeing the tool room from reconditioning work for the factory plant, and so extending the tool room capacity for jig, fixture, and gauge production.