Very often, there is difficulty in distinguishing between the various types of R&D activities and apportioning resources between them. This happens mostly in the headquarters of scientific agencies/departments where more of S&T-related activities are being done rather than R&D activities. The Indian reports adopt the definitions given in the UNESCO manual, which itself is a modified version of the OECD manual (popularly known as the 'Frascati' manual).

The national survey of R&D activities of DST does not cover the academic sector as the data collection faces dual problems — conceptual and operational. The academic sector is neither cohesive nor responsive. This is so since the faculty are involved in both research and teaching and are scattered in various S&T departments of the universities/postgraduate colleges. So, it is not easy to make them respond to the questionnaire, nor are the vice-chancellors or registrar's offices found to be of any help or effective. It is difficult to apportion expenditure between teaching and research except for sponsored (extramural) projects. Even for sponsored projects, data collection is extremely difficult from this sector, as the response rate is very poor.

Having outlined the mechanism of data collection and the problems encountered, it is useful to give a brief analysis on the share of R&D expenditure between different sectors over the last 15 years for which detailed data are available. The central government, excluding public-sector industry, accounts for nearly 70% of the national R&D expenditure, while state governments account for around 10%, and industry, comprising public and private sector, accounts for the remaining 20% of national R&D expenditure. This *inter se* share between sectors has not changed over the last several years. This is one of the important inferences drawn from the time series data on R&D expenditure. Likewise many more inferences/signals are possible using the trend of R&D expenditure within sectors/subsectors and between sectors. So R&D expenditure data and analyses can play a major role in understanding their trend so far and in deciding the desirable change in trend and priorities for the future. For such in-depth analyses, data on R&D budget/expenditure are extremely important and they should be reliable and made available in time.

Cost reduction through value engineering

C. G. Krishnadas Nair

Value engineering and value analysis are organized efforts with the aim of overall cost reduction without affecting the quality and performance of product/service; thus ensuring 'value for money'. Application of commonsense, logical and lateral thinking, willingness to experiment and innovate and reasonable knowledge of the subject matter are the basic requirements of value engineering. Best results are obtained when it is a team work with a multi-disciplinary group drawn from various departments such as, design production engineering, laboratory, manufacturing, quality, commerce and finance.

VALUE is the sum of those properties embodied in a product or service that enable it to accomplish its intended functions without sacrifice in any of the parameters of performance, cost and prompt delivery. A product or service is generally considered to have a good value if that product or service has appropriate performance and cost. Or, by reverse definition, a product is considered not to have good value if it lacks either appropriate performance or cost. Value can be increased by either increasing the performance or decreasing the cost. More precisely:

– Value is always increased by decreasing cost (while, of course, maintaining performance)

– Value increased by increasing performance if the customer needs, wants and is willing to pay for more performance

The value of a product depends on factors partly determined by its controllable characteristics such as the quantity and types of raw materials needed, the methods and procedures of manufacture, the performance specifications on which the design is based, and the like, and partly by circumstances and conditions outside the control of the designer such as changing market conditions and the vagaries of consumer demand. Anything that affects costs will of course affect value.

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Value engineering and value analysis are organized efforts to make a product accomplish a desired function at lowest cost and thus maximize its real value. The methods of achieving this goal are based on a systematic analysis of those factors that contribute to a satisfactory fulfilment of the functional requirements and of those that do not.

Value analysis is the systematic and methodical investigation/analysis of the process in providing service or in the manufacture of the product with the aim of overall cost reduction without affecting the quality and performance of product/service; thus ensuring 'value for money'. Value engineering is the application of value analysis in the design and manufacture of product. Value engineering is a study of all possible ways of developing product that will perform required and unequivocally defined functions at minimum cost. It is much more than cost cutting, as it is imperative that whatever changes made in the design, material, process of manufacture, quality assurance, etc. for cost cutting should not alter the performance of the component, system or equipment manufactured.

Value analysis is a problem-solving system implemented by the use of a specific set of techniques, a body of knowledge, and a group of learned skills. It is an organized creative approach that has for its purpose the efficient identification of unnecessary cost, i.e. cost that provides neither quality nor use nor life nor appearance nor customer features.

When applied to products, this approach assists in the orderly utilization of better approaches, alternative materials, newer processes, and abilities of specialized suppliers. It focuses engineering, manufacturing, and purchasing attention on one objective—equivalent performance for lower cost. Having this focus, it provides step-by-step procedures for accomplishing its objectives efficiently and with assurance.

Value analysis approaches may assist all branches of an enterprise—engineering, manufacturing, procurement, marketing, and management—by securing better answers to their specific problems in supplying what the customer wants at lower production costs. Quite commonly, 15 to 25 per cent and very often much more of manufacturing costs can be made unnecessary without any reduction in customer values by the use of this problem-solving system in the significant decision areas.

Basic requirements for value engineering are application of common sense, logical and lateral thinking, willingness to experiment and innovate, and reasonable knowledge of the subject matter. The persons involved in value engineering must have a questioning mind. They must ask and find answers to questions such as those given below, at the same time keeping in mind that no compromise is to be made on the product performance, reliability and maintainability.

- Can the design be altered?
- Can a cheaper material/method of fabrication be used?
- Can less material be used?
- Are all the operations and inspection stages and procedures indicated in the process sheet required?
- Is there some way to perform the function for less money?
- Could a standard part be used?
- Could a standard part be modified to serve the intended purpose more economically?
- Could the design be changed to eliminate or simplify the part?
- Could a stock item which has already been incorporated into another design be used?
- Could the part be made more economically from another material?
- Is the technique of forming the part the most economical?
- Are all tolerances and specifications specified required for the expected performance and reliability in service?

Few product designers and production engineers readily accept changes in their design/processes once these have been proved to function adequately. Value engineering must necessarily question and review these.

For this reason, best results are obtained when it is a teamwork with a multidisciplinary group drawn from various departments such as design, production engineering, laboratory, manufacturing, quality, commercial, finance, etc. A few case studies are presented here to illustrate how cost of production is cut down through the application of value engineering in a variety of products such as castings, forgings, machined parts, sheet metal and welded assemblies, composites, etc.

Case 1: Fin forging—saving in material

Foundry and Forge Division, Hindustan Aeronautics Limited, Bangalore Complex, had undertaken the manufacture of an aluminium–copper alloy close tolerance fin forgings required for anti-tank missiles (Figure 1). Approximate annual requirement was one lakh pieces.

The forgings were being produced from extruded bar stock of section 41 mm × 13 mm and 230 mm long. The forging stock weighed 327 g whereas the forging

Figure 1. Fin forging

weighed only 80 g, resulting in heavy loss of material as forging flash. A study of the geometry of the fin forging showed that the section drastically reduced from the fixed end to the other end. Hence the same bar stock split into two could easily be forged to the shape required. Further, it was possible to reduce the thickness from 13 mm to 10 mm. Additional material saving was also proposed by suggesting use of a profiled extrusion. The various improvements and effects are shown in Table 1.

Even though a few grams of metal only were saved at each phase of improvement in process, the impact on mass production was enormous. Value of cumulative savings has been worked out taking Rs 48 per kg for the alloy, and a scrap recovery value of Rs 10 per kg.

Case 2: Semi-continuous aluminium alloy billet—saving in material and labour

Foundry and Forge Division had developed semi-continuous cast billets in high-strength Al–Cu alloy for supply to a subcontractor for manufacture of profiled extrusions for aircraft structural applications. The approximate requirement of these billets had been 30 tonnes per annum. These billets were required to be of 150 mm dia to suit the particular extrusion press. The division was however casting 190 mm dia billets and machining the same to 150 mm dia, resulting in considerable wastage of labour and material. A study revealed that this method was adopted due to the poor surface quality of the billet, as shown in Figure 2. The circular ripple defect on the surface extended quite deep and at times resulted in puncture of the billet. Under constant conditions of water cooling of the mould and constant level of liquid metal, the billet withdrawal rate affected the geometry of solidification front as shown in Figure 3. Careful observations during billet casting revealed that surface defects were related to fluctuations of level of molten metal in the mould and fluctuations of billet withdrawal rate. A 165 mm dia mould was made and casting parameters were standardized to obtain billets of satisfactory surface finish (Figure 4) so that a light machining was adequate prior to extrusion.

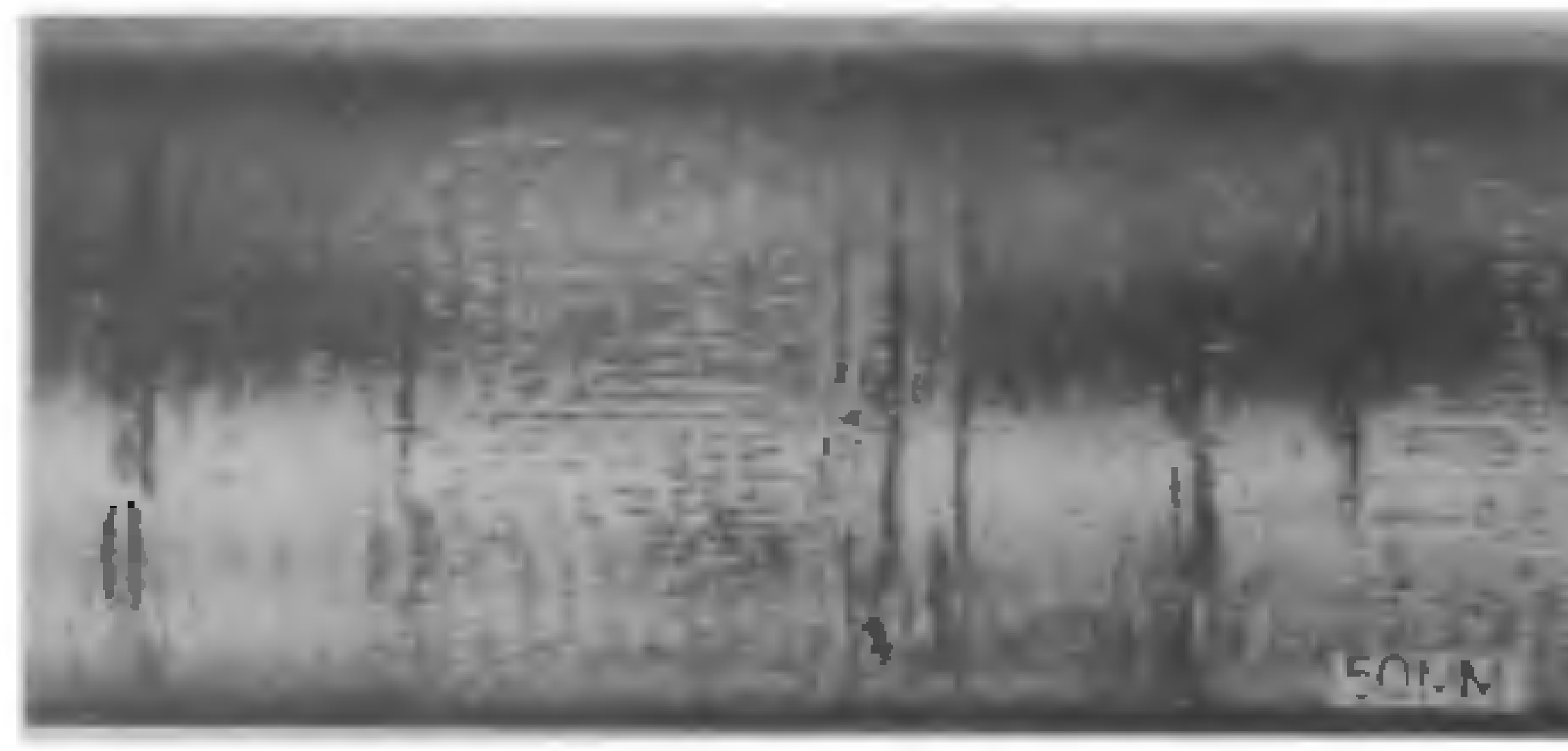


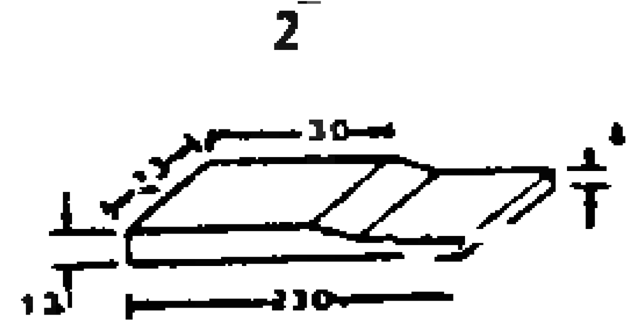
Figure 2. As-cast billet showing poor surface quality, 190 mm dia.

This cut down the cost of machining in addition to saving valuable material, and resulted in a total saving of about Rs 1.7 lakhs per annum as given in Table 2.

Case 3: Centrifugally cast cylinder liner—saving in material and labour

Foundry and Forge Division had developed an alloy cast iron cylinder liner casting for the L-60 engine of Vijayanta tank. It was a high-quality casting with 100% radiographic inspection. At the time of this work, forty liners per month were being produced, and there was a plan to increase the production to 150 per month. The alloy cast iron was melted in induction furnace and centrifugally cast into hollow cylinders. These were then

Table 1. Material economy in fin forging

Method	Forging stock sizing (mm)	Stock weight (g)	Material saving per piece (g)	Cumulative saving per annum (One lakh pieces)	
				Material (tons)	Value (Rs in lakhs)
Original	41 × 13 × 230	328			
Phase-1 improvement		164	164	16.4	6.2
Phase-2 improvement	$\frac{41 \times 13 \times 230}{2}$ 	134	30	19.4	7.37
Phase-3 improvement	Use of profiled extrusion	100	34	22.8	8.66

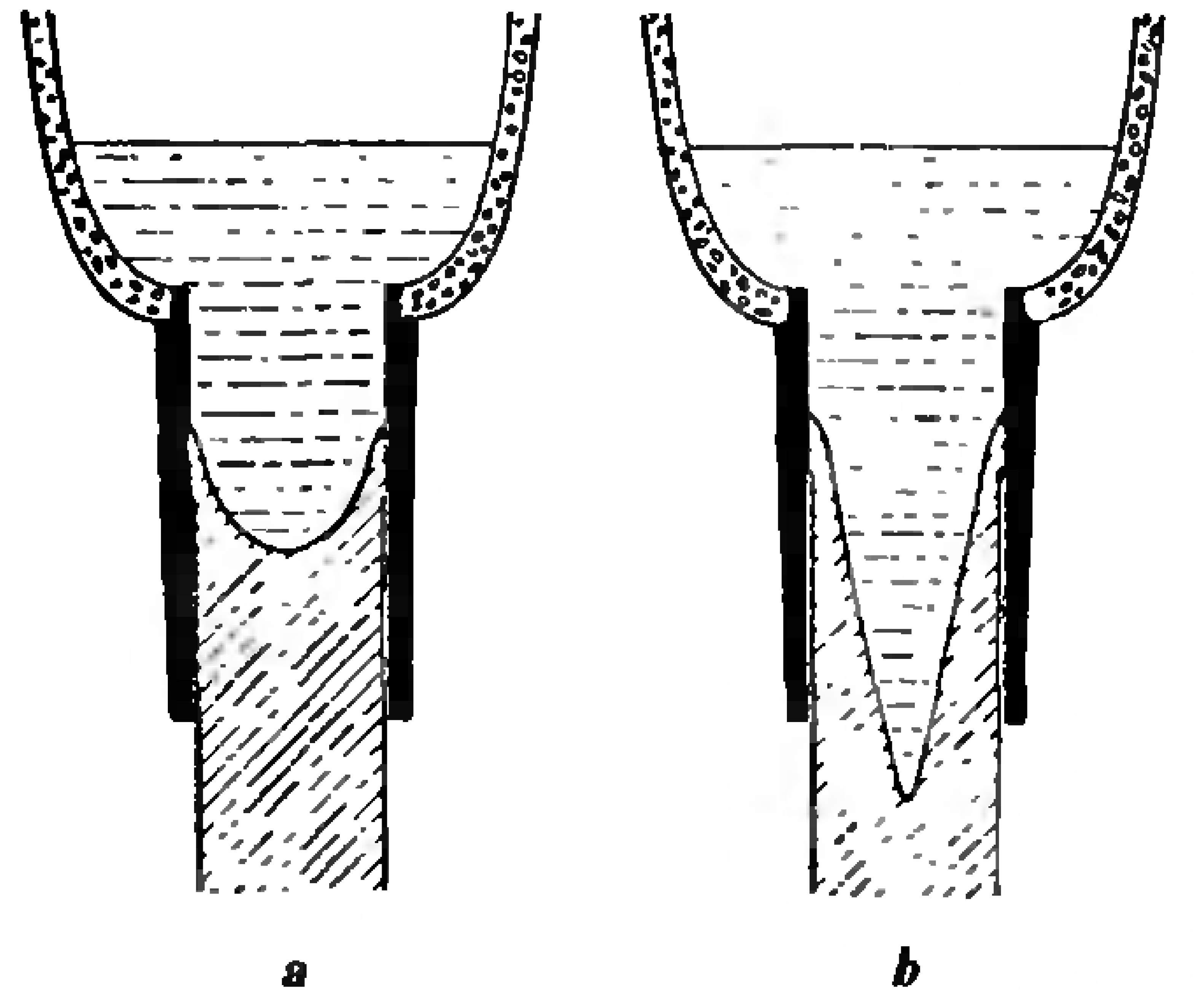


Figure 3. Geometry of solidification front in continuous billet casting: (*a*) slow withdrawal rate, (*b*) fast withdrawal rate.

Figure 4. As-cast billet with good surface quality after process improvement, 165 mm dia.

Table 2. The case of semi-continuous cast billet

Saving in material:	
Saving in material per billet	25%
Saving in material per annum	=25% of 30 tonnes=7.5 tonnes
At the rate of Rs 30 per kg for billet and Rs 10 per kg	
Scrap recovery, saving (Rs)	=(30–10)×7500=Rs 1,50,000
Saving in machining:	
Cost of machining	
1900 mm dia billet to 150 mm dia	=Rs 20 per billet (300 mm)
Cost of machining	
165 mm dia billet to 150 mm dia	=Rs 7 per billet
Saving per 30 tonnes (1800 billets)	=Rs 13×1800=Rs 23,400
Total saving per annum	=Rs 1,73,400 say Rs 1.73 lakhs

heat-treated, rough-machined, X-rayed to check soundness, and subsequently finish machined. Figure 5 shows as-cast, rough-machined and fully machined liners.

The as-cast part weighed 75 kg and rough-machined part and finish-machined part weighed 26 kg and 15 kg respectively. As there were many costly alloying elements, the alloy cast iron costed about Rs 12 per kg and it appeared therefore desirable to reduce the weight of the as-cast part and this would also reduce the extent of rough machining. The cost of rough machining was Rs 530 per liner.

Figure 5. Cylinder liner casting: (*a*) as-cast, (*b*) rough-machined, (*c*) fully machined.

A schematic of centrifugal casting is shown in Figure 6. Molten alloy is poured into a rotating mould, and the metal is distributed to the circumference of the cylindrical mould radially by the centrifugal force. The centrifugal force however drives the denser alloy to a greater distance (radially) than the less dense nonmetallic inclusions and impurities. Thus the impurities get concentrated towards the inside surface of the cast cylinder.

This was why a liberal wall thickness and machining was provided for the cast cylinder. However, with better control over melt quality it would be possible to increase ID and thus reduce the casting weight. This was implemented and a saving of 10 kg per casting was realized. This, at the rate of Rs 12 per kg, resulted in a saving of Rs 120 per casting, with a bonus saving of Rs

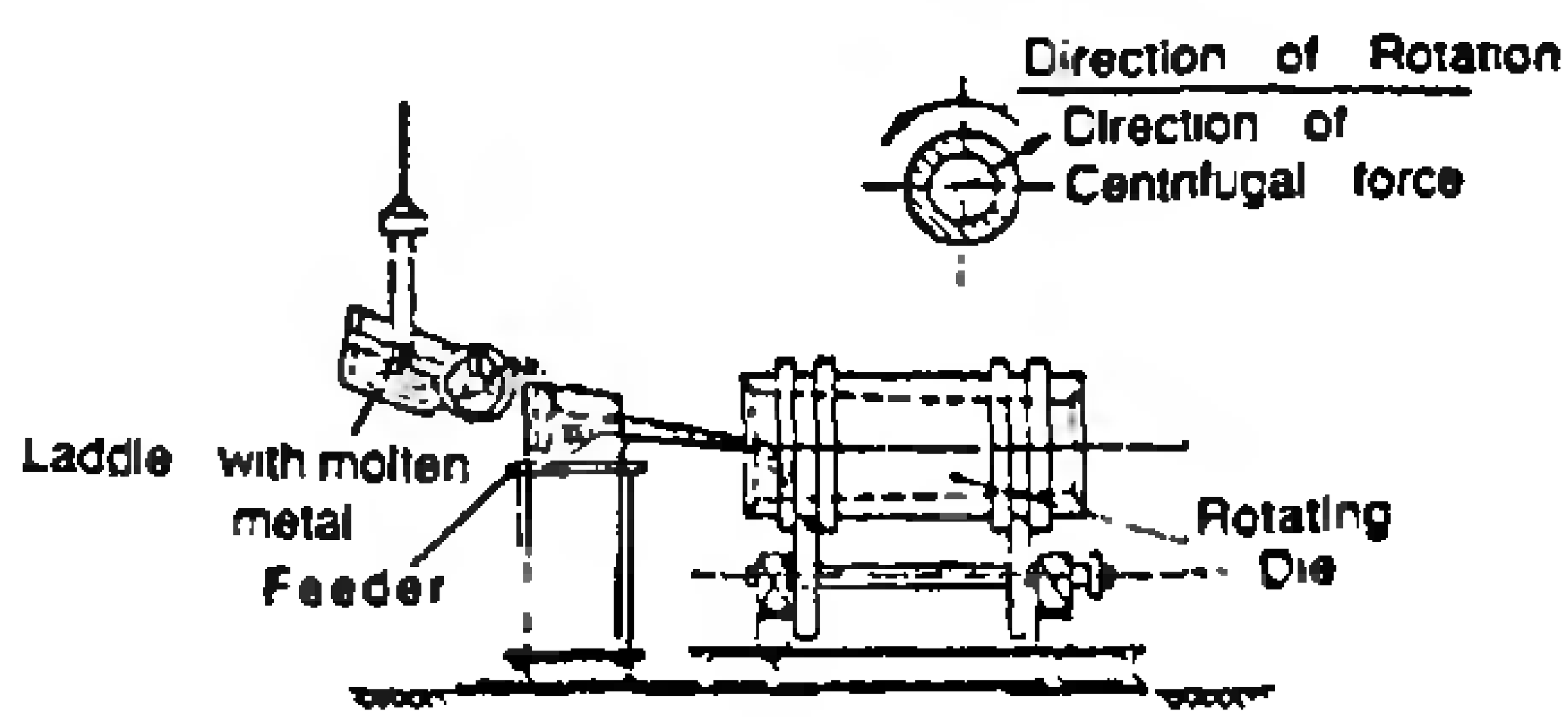


Figure 6. Schematic view of centrifugal casting.

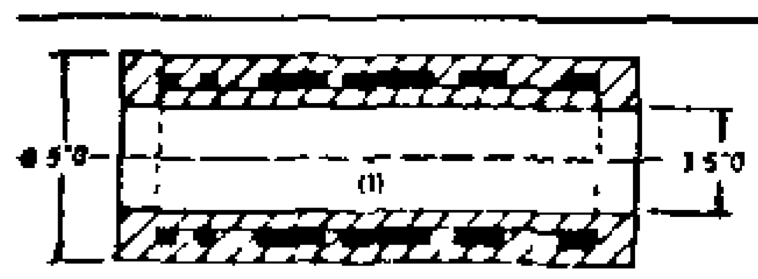
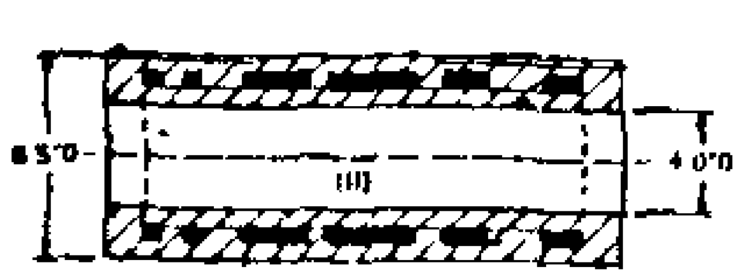
40 for machining. Later the production rate was increased from 40 to 150 per month and saving on account of this improvement was Rs 2.88 lakhs per annum, as illustrated in Table 3.

Case 4: Latch and safety plug body forging — a design change

Foundry and Forge Division, Hindustan Aeronautics Limited, Bangalore Complex, was to manufacture the subject forging in a high-strength aluminium alloy for a defence equipment under design and development. On examination of part drawing of the component (shown in Figure 7), it was found to be designed as a die forging, whereas its shape was also conducive to its manufacture as an extrusion.

It was considered that the functional requirements of the component could also be met by an extrusion, and this was confirmed during discussions with the designer. Since the manufacture of the item as an extrusion would result in considerably less expenditure in terms of tool and labour costs, the design was changed to an extrusion, as suggested by us. A comparison of the cost of production by the two methods of manufacture is given in Table 4. Timely feedback from the manufacturer to the designer considerably reduced the cost of the component, resulting in a cheaper product to the satisfaction of the designer and user, without any sacrifice to quality.

Table 3. Cylinder liner casting—cost saving by change of casting geometry

Casting geometry	Weight (kg)		Saving per casting	Saving per annum (1800 pieces)
	75			
	65	Material (10 kg)	Rs 120	Rs 2.88 lakhs
		Machining	Rs 40	
		Total	Rs 160	

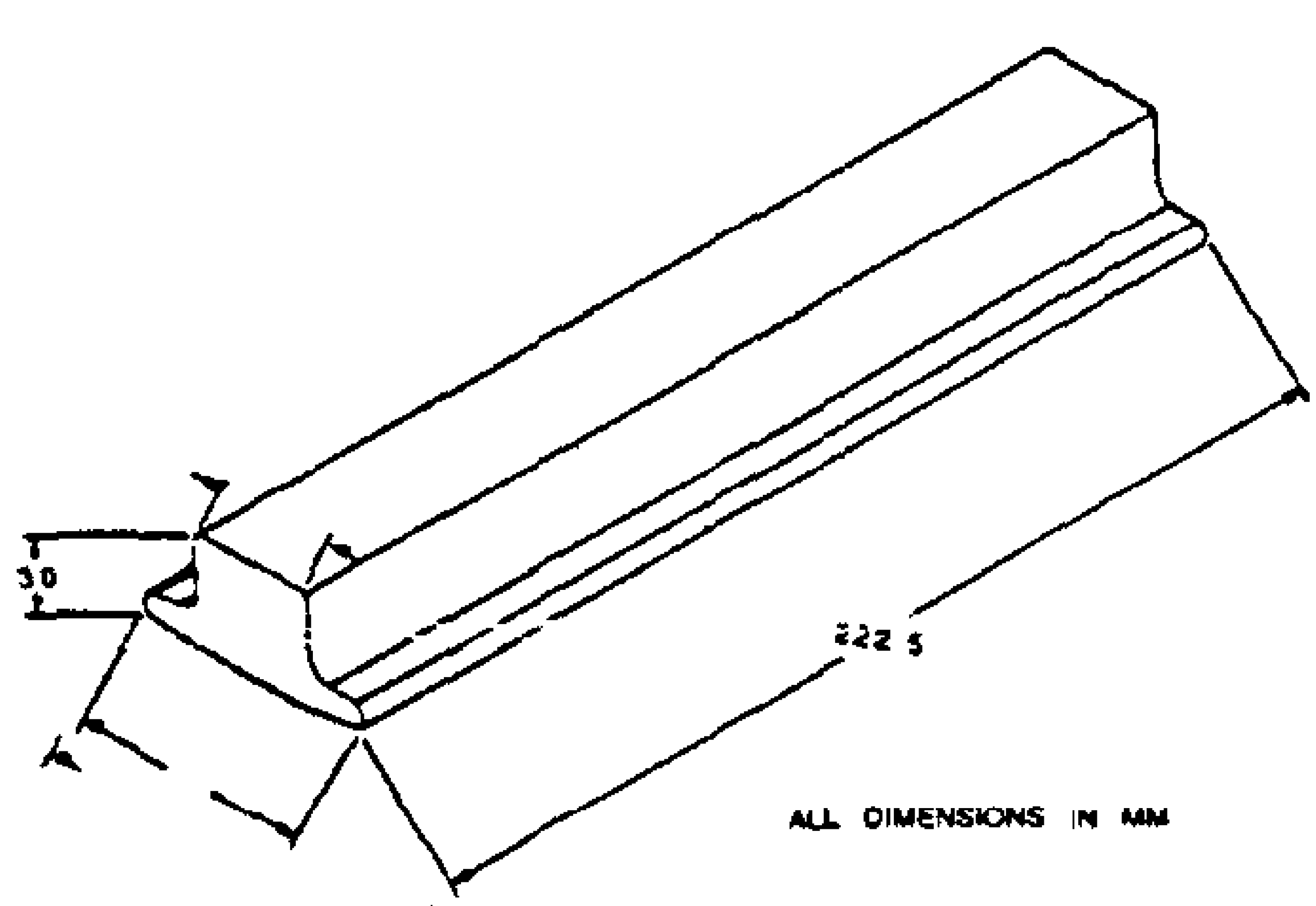


Figure 7. Latch and safety plug body forging (extrusion?).

Table 4. Comparison of costs — latch and safety plug body forging

	Forging	Extrusion
Tooling cost	Rs 40,000	Rs 2,500
Production cost:		
Material cost per piece	Rs 55	Rs 30
Labour cost per piece	Rs 190	Rs 44
Net saving per piece		Rs 171
Saving for total requirements (5600 pieces)		Rs 9,576 lakhs

Case 5: Housing forging — a method change

A housing forging in En-8 steel required for a defence project was being developed and manufactured by Foundry and Forge Division. The method employed consisted of several operations such as upsetting, piercing, mandrel forging, axial pressing and two stages of die forging as shown in Figure 8.

The process was simplified to a single upsetting followed by three-stage die forging, with a drilling operation between second and third die forging operations, as illustrated in Figure 9. To avail the simplified method, a slightly larger bar stock had to be used, amounting to 1.5 kg excess steel. This, at the rate of Rs 8 per kg, worked out to an excess cost of Rs 12 per forging. The saving on account of labour and machine utilization was estimated at Rs 143 per forging.

After implementation of the new method, the total saving over 900 pieces was Rs 1.287 lakhs.

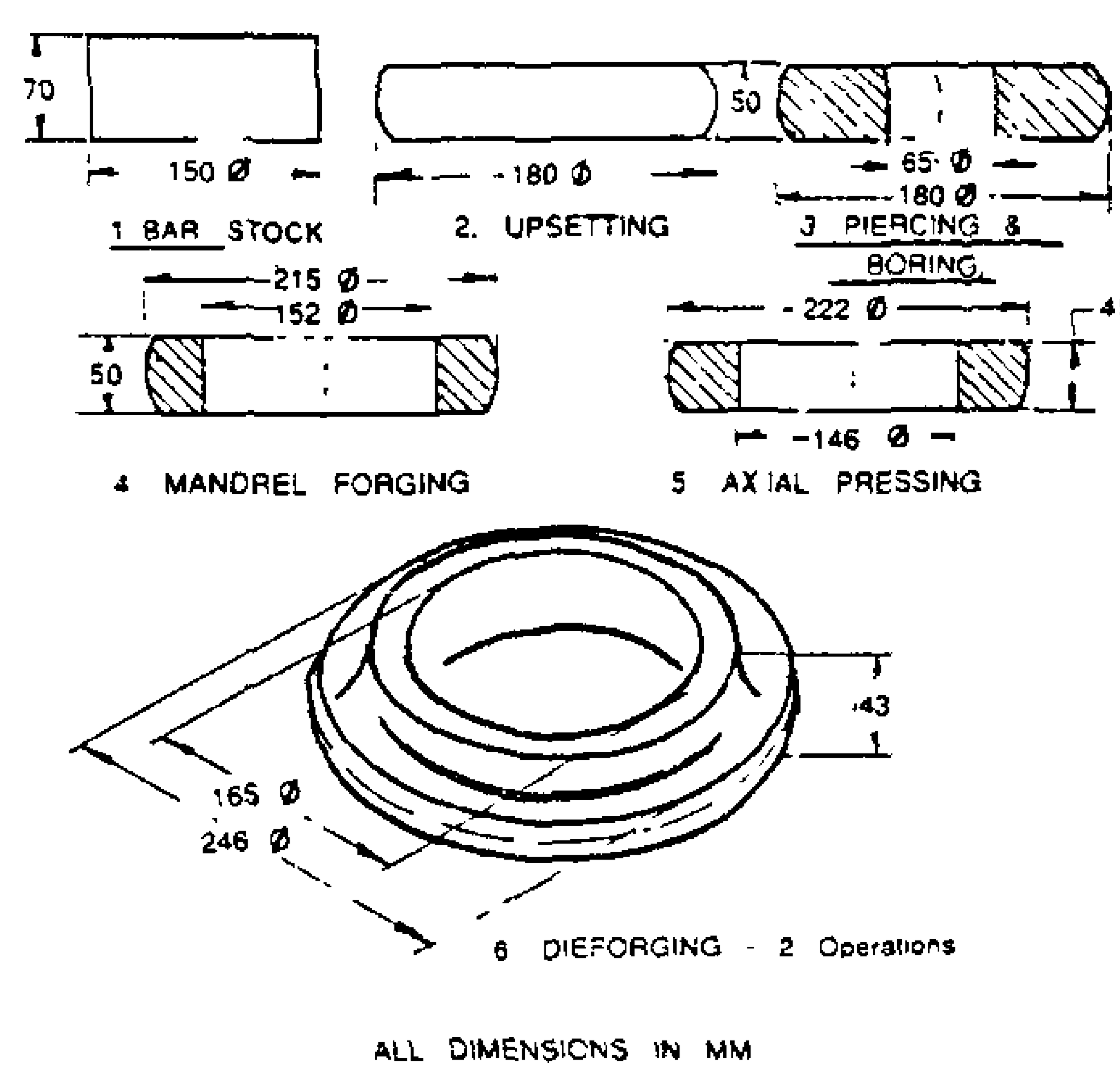


Figure 8. Housing forging, old method.

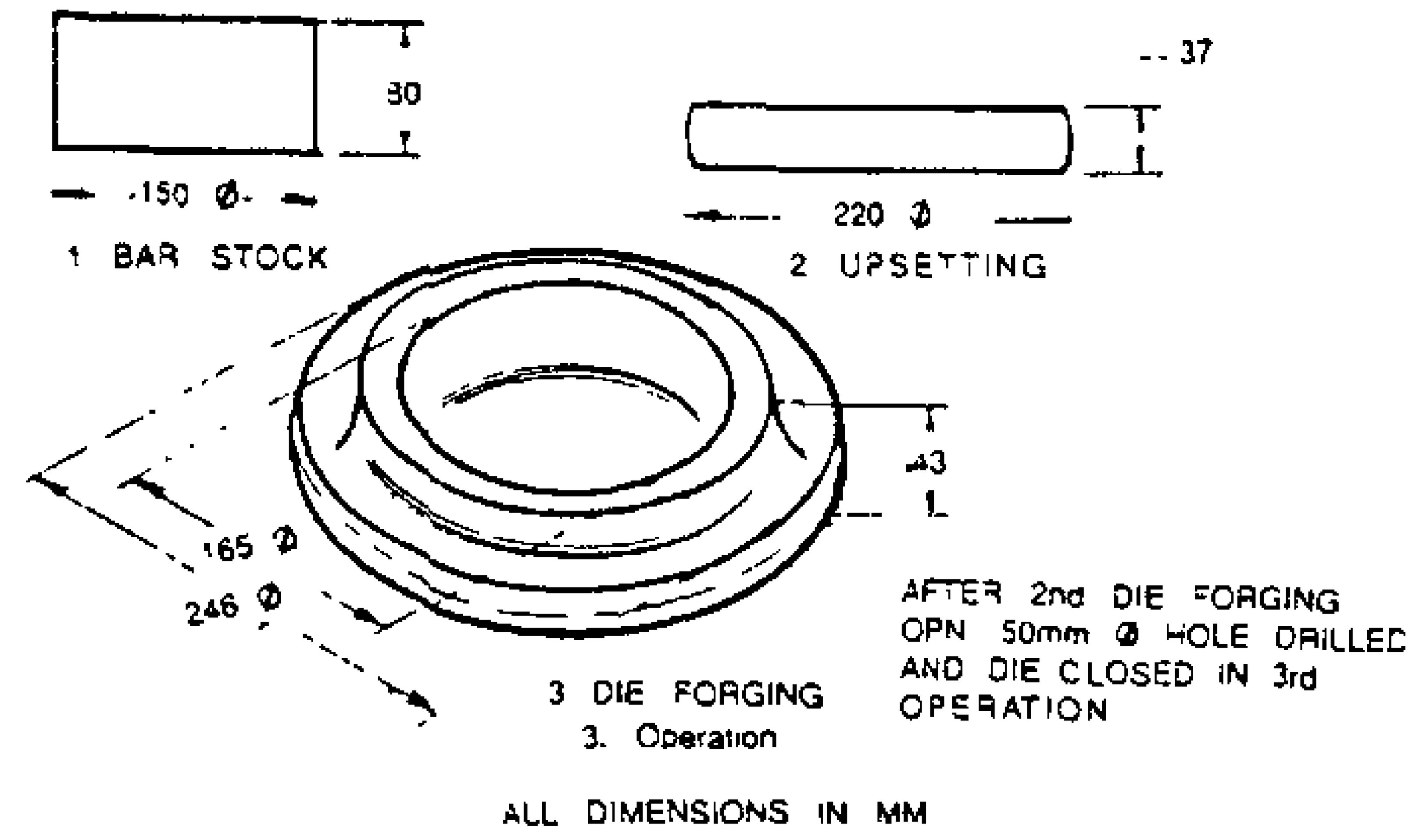


Figure 9. Housing forging, new method.

Case 6: Missile forgings — avoidance of wasteful operations

Critical review of sequence of manufacturing operations of components for which production has been stabilized can often lead to identification of avoidable and wasteful operations. Resequencing of operations can also make some of the original ones redundant. In this manner improvements in processes can be effected, thereby saving avoidable labour hours and auxilliary materials used in production.

A typical example is the case of a *missile forging* made of an aluminium alloy. As per the original process 26.54 man-minutes were required per piece for the production of this item as illustrated in Table 5. On review, it was found that the billet polishing was once introduced when raw material obtained had some surface scratches. This later became part of the routine operations, whether polishing was really required or not. Examination of the raw material showed that polishing was to be employed only on cases where raw material was heavily scored. Hence this operation was to be eliminated from the main process sheet and introduced as an additional operation as and when required, at the discretion of the production engineer. Probability for this need being less than 20 per cent, a saving of approximately 1.4 minutes per piece was realized. Also, it was considered that operations 6 and 9 could be eliminated in view of the later operations 10 and 15. By introducing an inspection stage immediately after operation 15, operation 16 was eliminated as the time required for rework, if any, had already been included in operation 15. At this inspection stage the inspector was made responsible for making the batch identification and thus eliminating operation 7. Further, in operation 8 (degrease and etch), the etching was eliminated as this was prior to heat treatment. Etching would be necessary only if the parts were to be inspected at this stage.

Thus a saving of 5.2 minutes per piece was realized. A number of experimental batches were run, eliminating the extra operations, and it was established that the revision of methods had not affected the quality of the component in any way, and accordingly the same was regularized for production. Saving in cost of production *per piece was estimated at Rs 3.46 at a man-hour rate* of Rs 40. For a production rate of 70,000 pieces (average) per year, the saving was Rs 2.42 lakhs per annum.

As a further improvement a special trimming tool to trim the forging as was done for the precision blade forgings was developed to substitute operation 15

Table 5. Comparison of old and new operations for production of missile forgings

	Old method				Present method				
		Allowed time		Unit time		Allowed time		Unit time	Saving per unit
Operation	Qty	(h)	(min)	(min)	Qty	(h)	(min)	(min)	(min)
Bar stock cutting	500	—	—	0.40	500	—	—	0.40	—
Billet polishing	500	15	0	1.80	—	(optional)		—	1.40
Degrease and etch	500	3	15	0.40	500	3	15	0.40	—
Finish forging	500	20	00	2.40	500	20	00	2.40	—
Band saw flash	500	10	00	1.20	500	10	00	1.20	—
Debur flash lines	500	10	00	1.20	—	—	—	—	1.20
Mark batch no.	500	3	00	0.36	—	—	—	—	0.36
Degrease and etch	500	3	14	0.40	500	1	30	0.18	0.22
Hand straighten	500	5	00	0.60	—	—	—	—	0.60
Coining	500	15	00	1.80	500	15	00	1.80	—
Degrease	500	1	30	0.18	500	1	30	0.18	—
Turn tensometer	500	1	00	0.12	500	1	00	0.12	—
Profile mill	500	12	00	1.44	500	12	00	1.44	—
Shear ends	500	8	00	1.00	500	8	00	1.00	—
File to suit gauges	75	13	00	10.80	75	13	00	10.00	—
Rework to suit gauges	500	12	00	1.44	500	—	—	—	1.44
Degrease and etch	500	3	15	0.40	500	3	15	0.40	—
Ardox	500	5	00	0.60	500	5	00	0.60	—
				26.54				20.92	5.22

which involved considerable amount of bench work by skilled workmen. The time for operation 15 was reduced from 10.8 minutes to 4.8 minutes per piece and this resulted in additional saving of Rs 2.8 lakhs per annum.

Total saving for all the operation changes was Rs 6.2 lakhs per annum.

Case 7: Outer guide vane assembly — saving in labour and material

Outer guide vanes of an advanced jet engine are assembled after matching of the vanes with outer and inner duct casings as shown in Figure 10. After the assembly, the parts are vacuum-brazed with Orobraze M.S.950 118 wire and Orobraze powder 950. These consumables containing 80% gold are costly items. The consumption of the powder was of the order of 180 g per part whereas the recommended quantity as per collaborator's process was only 150 g.

The outer duct vane slots and the vanes are manufactured by press tools and the inner duct vane slots are produced by electric discharge machining (EDM). Assembly of the items posed considerable difficulties as the desired gap between the vane and slot could not be ensured, thus necessitating frequent rework which consumed more labour hours.

The problem was analysed systematically to cut down the labour hours and consumption of the costly Orobraze powder. The slots on the inner duct were found to be on the higher side of the tolerance. Special profile electrode was manufactured to produce close tolerance vane slots. The inner duct thus produced aided in better assembly for which the fitting and dressing time could be substantially minimized.

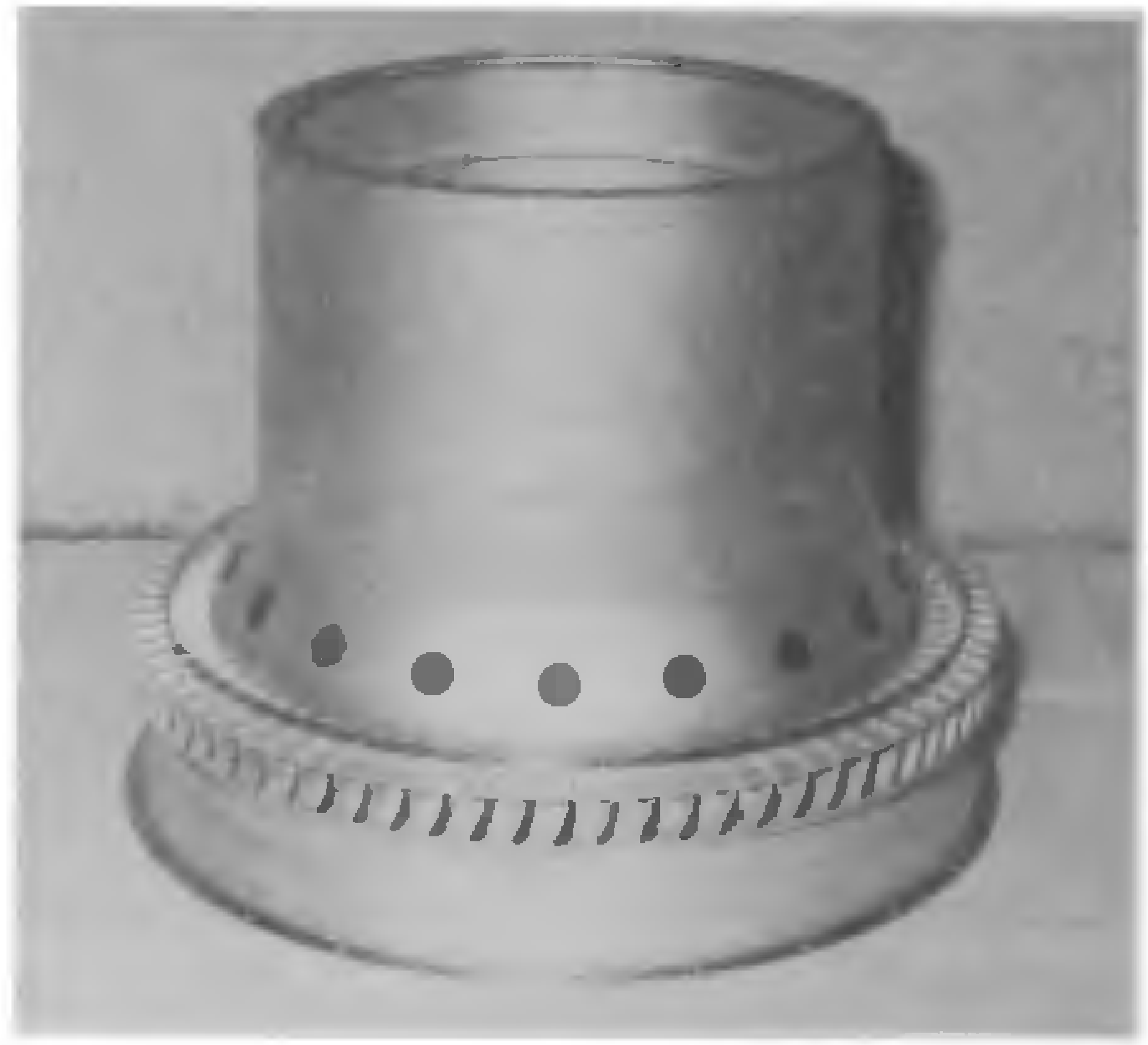


Figure 10. Outer vane assembly.

Orobraze 950 consumption was reduced by closing the large gaps to increase the capillary action, careful and controlled application of the braze material with the help of a brazing dispenser, avoiding runs and lump formations and by avoiding/minimizing rework. These and use of brazing cement 601 as the brazing carrier instead of Nicro Braze 200 to eliminate loss of braze metal due to sputtering while brazing reduced the consumption of the powder to a level much lower than the consumption norms indicated by the collaborator resulting in substantial saving. Computation of saving is given below in Table 6:

Table 6. Computation of saving

	Before study	After study	Saving
Saving in labour hours Fitting work operation No. 005 & 060	90 man-hours	63 man-hours	27 hours
Vacuum brazing Operation No. 150 & 160 inclusive of rework when required	14 man-hours	8 man-hours	6 hours
Total saving in labour			33 hours
Saving in material			
Orobraze powder 950	180 grams @ Rs 720 per g = Rs 1,29,600	120 grams @ Rs 720 per g = Rs 86,400	
Cost saving due to material/part = Rs 1,29,600–86,400			Rs. 43,200
Cost saving due to labour @ Rs 130 per h = 130 × 33			Rs 4,290
Total saving per part			Rs 47,490
Estimated saving for the project (70 engine sets)		47,490 × 70	Rs 33,24,300 or say Rs 33 Lakhs

Case 8: Low-pressure stator vane assembly stage-2—process improvement

Low-pressure (LP) stator vane assembly shown in Figure 11 has two subassemblies, viz. LP-2 vane front and LP-2 vane rear, each consisting of 41 vanes. These are produced by electron beam welding (EBW) of the vane segments and assembly followed by heat treatment and final machining. Statistically it was observed that out of twelve assemblies produced 58% were accepted with deviation under concession. Problem commonly noted was reduction in wall thickness after final machining. This was attributed to excessive distortion/ovality observed at the time of final machining wherein geometrical requirements had to be met finally by reducing the wall thickness. Also more time was consumed in truing up the component for final machining to balance for minimum metal removal.

A study was undertaken to assess the extent of distortion developed at each stage of manufacture and improve the process to minimize the same. The welding sequence in EBW was analysed and optimized for welding of blade sector; and for welding the vane assembly. This resulted in bringing down the ovality of the casing within 0.3 mm. During the stress relieving, the part was kept on a special flat support so that sagging of the part was avoided. After heat treatment the ovality could be contained within 0.4 mm, which was well within the technology limits. These steps resulted not only in improving the quality but also brought down the time required for setting up and finish machining as the distortion was minimum and special measures to compensate for the distortion (which were earlier required during machining) were no longer required.

The actual saving in labour hours due to improved processes and estimated total saving are given in Table 7.

Case 9: Open impeller 'A' and 'B' and grate change of product design to precision investment casting

The subject components required for a liquid propellant engine programme were designed to be machined out of bar stock. A value engineering study revealed that these components are more economically produced as precision investment casting and the vane machining operation which will take considerable amount of time could be completely eliminated. Figure 12 illustrates open impeller machined from bar stock and investment casting as per the old and new method respectively. The cost–benefit analysis due to introduction of investment castings in place of bar stock is given in Table 8.

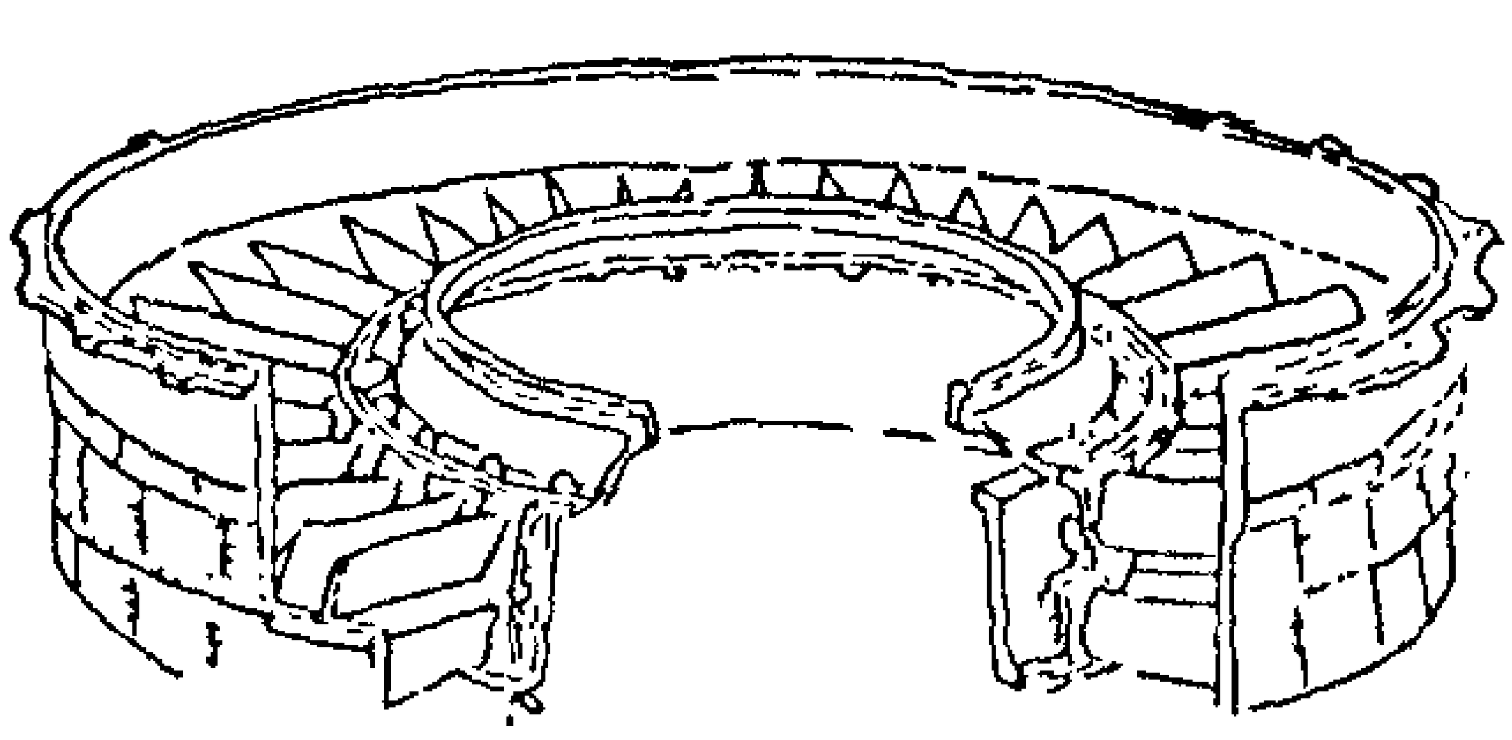


Figure 11. LP stator vane assembly.

Table 7. Computation of saving

Saving in man-hours for machining and heat treatment	= 12 1/2 hours per part
Saving in cost per part @ Rs 130 per h	= Rs 1,625
Estimated saving for the project (for remaining production of 70 engine sets)	= Rs 70 × 1625 = Rs. 1,13,750
Estimated saving during overhaul (for next 10 years @ 30% replacement)	= Rs 81,250
Estimated total saving	= Rs 20,44,000

Case 10: Pressed sheet metal parts—alternative method of manufacture and saving in capital expenditure and cost

Liner, support, plate, skirt and combustion chamber cap are heat-resistant alloy sheet metal items used on the combustion chamber assembly and stator compressor housing assembly of a turboprop jet engine. They are made out of corrosion and heat-resistant nickel alloy sheets to AMS 5536/AMS 5596 specification. The thickness of these components vary from 0.025 inch to 0.125 inch.

These sheet-metal items having complicated profiles are formed on hydro forming press as per the collaborator's process. The hydro forming process

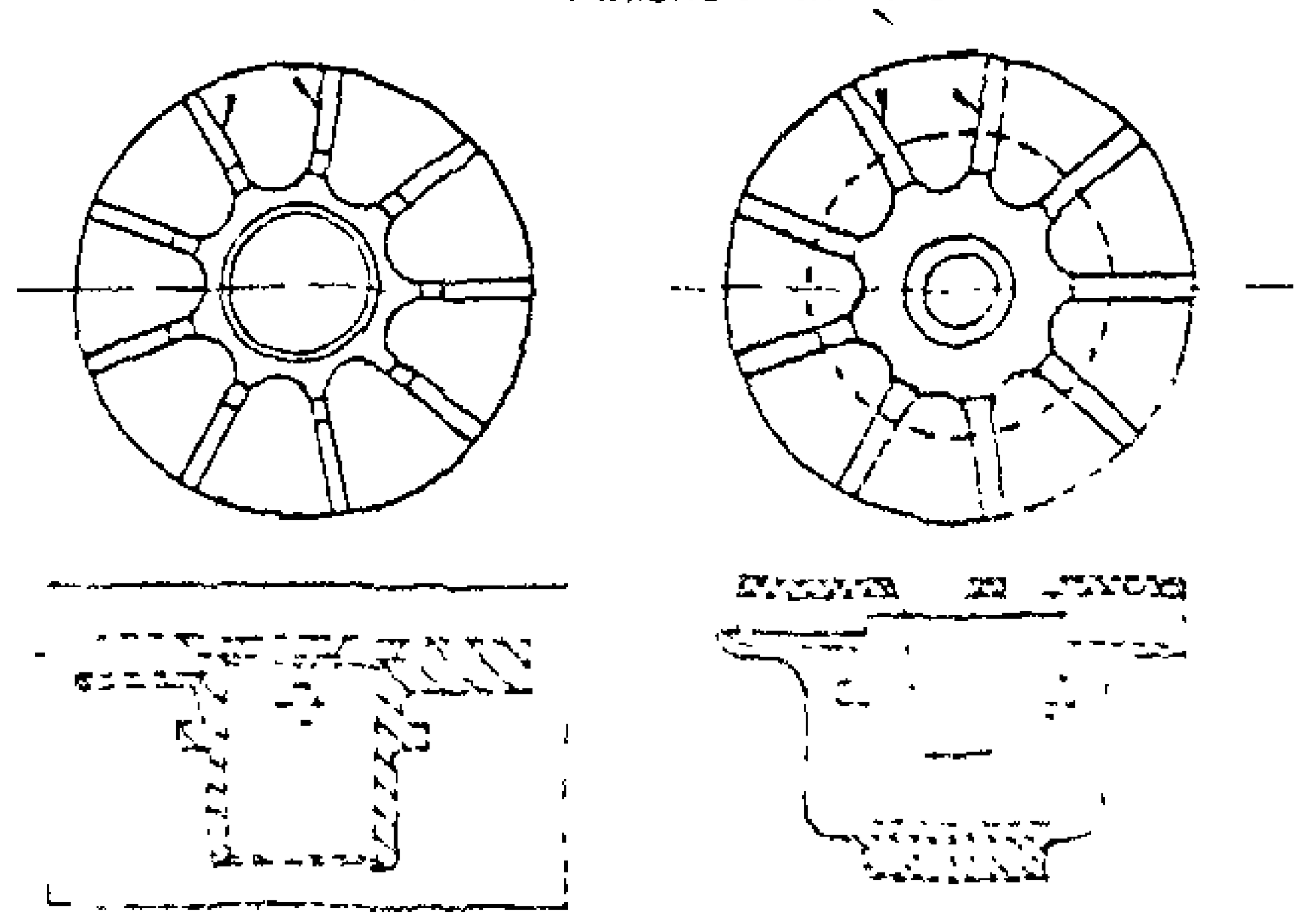


Figure 12. Open impeller, two alternative product designs.

Table 8. Cost saving by change of product design to investment casting

Component	Old method (bar machining)	New method (investment casting)	Saving
1. Open impeller-A			
Material cost	Rs 250 (SS Bar 30 Cr 13 IS 6003 55 dia bar × 40 mm long)	Rs 1,400	Rs 1,150
Machining cost	(17 h @ Rs 130) Rs 2,210	(6 h @ 130) Rs 780	+ Rs 1,430
Saving per part			Rs 280
2. Open impeller-B			
Saving per part	Same as above		Rs 280
3. Grade			
Material cost	Rs 100 (St. steel dia 60 × 25 mm long)	Rs 660	Rs 560
Machining cost	(6 h @ Rs 130) Rs 780	Nil	+ Rs. 780
Saving per part			Rs 220
Total cost saving per engine set (Rs 280 + 280 + 220)			Rs 780

Estimated saving for the project (for 810 engine sets) Rs 6.3 lakhs

Table 9. Computation of saving

		Foreign exchange
Cost of imported components	Rs 22,332	Rs 22,332
Cost of production by alternative method	Rs 8,792	Rs 5,594 (imported raw material)
Saving per engine set	Rs 13,540	Rs 16,738
Estimated saving for the project (275 engine sets)	Rs 37.235 lakhs	Rs 46.03 lakhs

utilizes hydraulic pressures, predetermined for the task up to as high as 15,000 psi. This pressure is applied against a flexible diaphragm which replaces the female die. The flexible diaphragm and programmed variable forming pressure make possible deep draws.

Hydro forming facility is not available at Engine Division. Procurement of this facility will not be cost-effective considering that the cost of the machine is around Rs 70 lakhs at 1987 price level and the quantity required for the entire project programme will account for only a low-percentage machine utilization. Hence it was decided to import the components until an alternative method of manufacture was established.

As such, an alternative method of making the parts on a 275-ton double-action hydraulic press by forming in stages was considered and the sequence of process was systematically developed and optimized to avoid

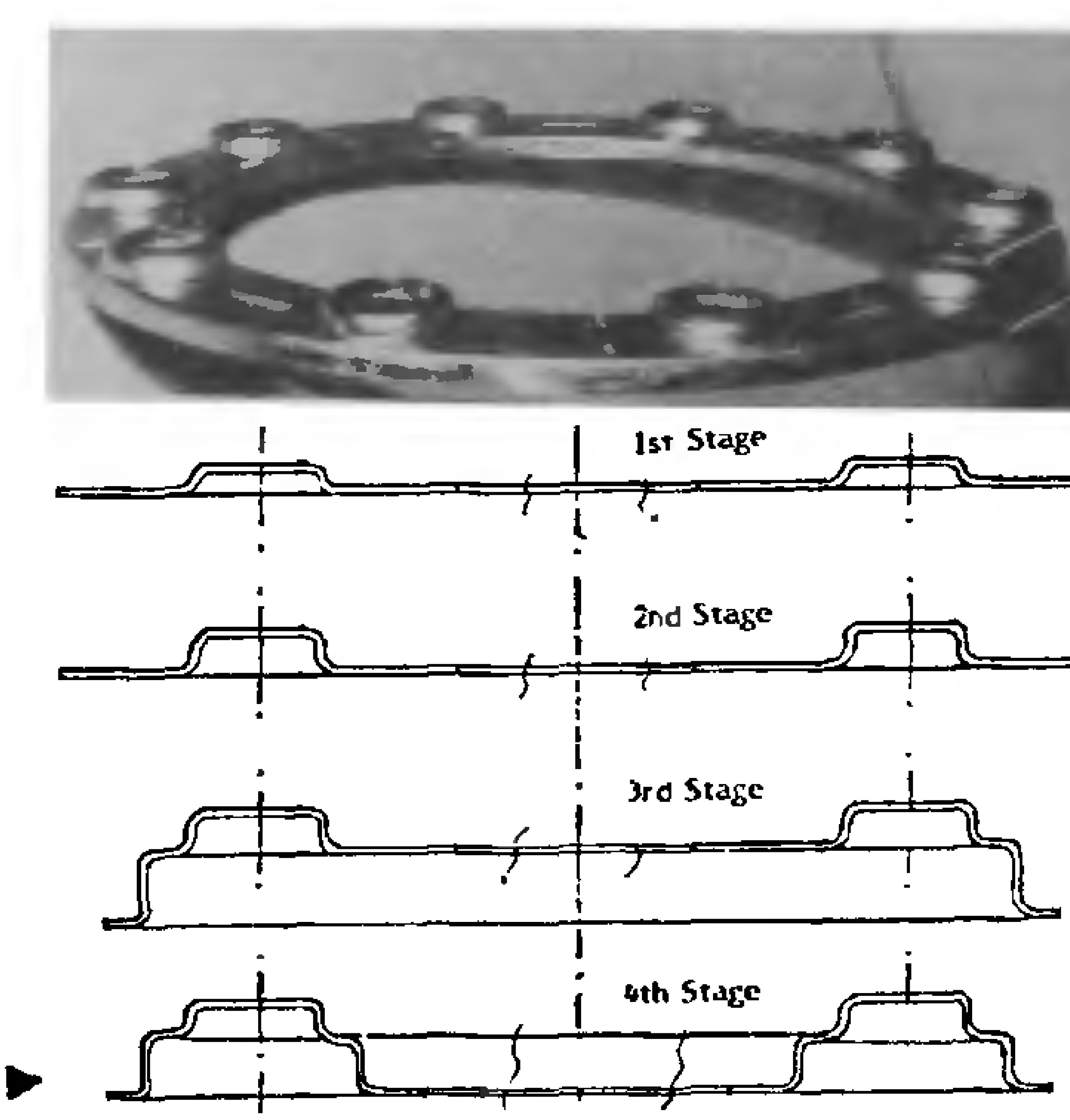


Figure 13. Combustion chamber cap and stages of forming by alternative method.

localized thinning and to meet the component drawing requirements.

Photograph of one component namely the combustion chamber cap and the various stages involved in forming the same on a hydraulic press is shown in Figure 13.

In addition to saving in capital expenditure, the above action has resulted in substantial cost saving in F.E. as otherwise these components should have been procured from the US. Computation of cost saving as well as saving in F.E. is given in Table 9.

REVIEW ARTICLE

Protection by caffeine against oxic radiation damage and chemical carcinogens: Mechanistic considerations

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There is little doubt that caffeine administered after exposure to UV light enhances the damage to cells and organisms by inhibiting photoreactivation, excision and/or recombinational repair. However, when already present in the system, it affords remarkable protection not only against O_2-dependent component of radiation damage, but also against chemical carcinogens that require metabolic activation. I discuss here possible mechanistic aspects briefly.

Early experiments

A little over 40 years ago, Witkin[1] demonstrated that post-treatment with caffeine reduces the survival, but dramatically increases the mutation frequency of UV-irradiated *Escherichia coli* cells. Between then and the early seventies, several papers[1-8] dealt with potentiation of the UV-induced damage in a variety of prokaryotic and eukaryotic cells and also suggested that caffeine possibly inhibits photoreactivation, excision repair and also the recombinational repair. It had been well known by then that the photoproducts of UV radiation largely consist of cyclobutane type of thymine–thymine dimers than cytosine–cytosine or thymine–cytosine dimers. From mechanistic point of view, scores of these papers allow us to state that in order to potentiate, caffeine must be administered *immediately after* the treatments with UV; pre-treatment with caffeine exerts no discernible effect. However, in marked contrast to the damage induced by UV, that induced by X-rays in mouse L[5], *E. coli*[9] or Ehrlich ascites tumour[10] cells are not affected by post-treatment with caffeine. Several experiments with *Secale cereale* and *Vicia faba* conducted in Warsaw[11,12] and Uppsala (Sweden)[13,14] failed to demonstrate the potentiating action of caffeine on chromosomal aberrations induced by X-rays. Similarly, caffeine post-treatment did not enhance the X-ray-induced chromosomal aberrations in Chinese hamster cells[14].

Two papers of particular interest are those of Yamamoto and Yamaguchi[15] and Ahnström and Natarajan[16]. Both these groups had used barley seeds as test system, and gamma rays as the radiation. Towards the end of this review, it would be evident that an insight into mechanistic aspects has been gained largely with the help of barley seeds exposed to ^{60}Co gamma rays. Yamamoto and Yamaguchi[15] concluded that caffeine increases the frequency of gamma ray-induced fragments by inhibiting the rejoining of chromatid breaks. Since caffeine was ineffective when added 30 min after irradiation, it was inferred that the rejoining process is completed within 30 min after the gamma irradiation. Ahnström and Natarajan[16] found that when barley seeds were exposed to gamma rays and then exposed to caffeine for the first 5 h of the germination period, the frequency of gamma ray-induced dicentrics and rings doubled. When the interval between irradiation and caffeine post-treatment exceeded 5 h, no enhancement of the radiation-induced aberration frequency was obtained.

A very significant observation[16], however, is that caffeine has no potentiating effect on the frequency of dicentrics and rings when neutrons are used instead of gamma rays. This observation that caffeine potentiates the gamma ray but *not* neutron-induced damage in the barley seeds raised a question, about 20 years ago in