ISSN 1012-277X S.Afr.j.ind.eng.

S A Journal of Industrial Engineering, Vol 4, No 2 December 1990 pp.30-42

MANUFACTURING ORIENTED DESIGN IN SMALL AND MEDIUM SIZE FACTORIES

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ABSTRACT

Special circumstances and considerations for the implementation of Computer Integrated Manufacturing principles in small and medium size factories are identified and discussed. An approach for esthablishing such programs is suggested and illustrated with a number of examples.

OPSOMMING

Spesiale omstandighede en oorwegings vir die implementering van Rekenaargeïntegreerde Vervaardigingsbeginsels in klein en mediumgrootte fabrieke word geïdentifiseer en bespreek. 'n Benadering vir die daarstelling van sodanige programme word voorgestel en geïllustreer met behulp van verskeie voorbeelde.

1. INCREASING IMPORTANCE OF SMALL AND MEDIUM SIZE FACTORIES (S.M.F.)

1.1 Small and medium size factories (S.M.F.)

The specific role of small and medium size factories as partners in our economic life as well as subcontractors of larger concerns cannot be underestimated. The problems which they encounter differ from those of large concerns. The flexibility that is required by their operation is typical, and is often much wider than of larger manufacturing units. The possibility of financial investment in an S.M.F. is limited, in the same way the time and effort their engineers can spend on long range research is also limited. The type of computer hardware and the cost of programs suited for their operation require specific solutions. Their particular technological expertise is generally large and should be integrated in a computerised expert system. In addition S.M.F. should introduce computer aided methods, which often must be tailor made, while retaining compatibility as modules to be fitted into larger units.

1.2 Advisory services

In an attempt to better serve S.M.F. our industry organised a cooperative advisory service combined with a dedicated research centre working in close cooperation with University Departments. This type of interface already exists for thirty years in Belgium, and is now being organised in the United States as "Manufacturing Research Institutes" [10] which facilitate the exchange of information and the transfer of research results between Industry and Universities. The staff members of these organisations help Industry to formulate their problems, for presentation to Universities providing students with industry related thesis material. Consequently many industrial problems are solved at minimum cost and an appropriate solution can be implemented. All programs presented hereafter have been developed in close cooperation with S.M.F. From a technical point of view this has given a special character to these programs, since they have been conceived with high modularity to guarantee great adaptability when implemented in different factories. It is a fact that every factory, small or large, has its own equipment, procedures and decision schemes. The programs have all been conceived to limit the cost of implementation. An extensive study was made of the organisation of the program to separate that which belongs to a common core of procedures and that which is firm specific.

2. THE LARGE MANUFACTURING CONCERN VS S.M.F.

Generally the goals when introducing CIM (Computer Integrated Manufacturing) in S.M.F. and large manufacturing concerns such as increased efficiency, better use of investment, reduction of lead time, better quality and reliability of the product, decrease of repetitive tasks and human failure, are the same, but there are also major salient differences:

2.1 In the fist place the concept of flexibility itself has different meanings in the two situations. When dealing with a large concern such a move means a transition from a rigid organisation with a strong hierarchical line toward more flexibility, a larger delegation of the decision making power toward the relevant level, and generally the replacement of rigid automatic machines or ultra rigid transfer lines with manufacturing cells. In an S.F.M. introducing CIM generally means going from a very flexible personalized organisation toward a more rigid one. Work preparation, planning etc. generally left to "the experience" of the "execution level" are seldom optimized.

2.2 In a large concern standardisation, planning tool management and line balancing cost price are well known principles. In an S.M.F. one "gets things done" where the man on the floor intuitively adds missing information. In practice this may differ from person to person so that tooling costs or machining time may differ significantly.

It generally takes a long period of instruction for young people to really get acquainted in the firm with specific design and production techniques.

2.3 In a large concern, design and manufacturing are mostly performed in the concern itself, so that a good feedback from manufacturing to design can be secured, although the gap between the design office and manufacturing floor is often difficult to bridge! [2][6]

In many small firms, especially job shops, the design is produced by someone outside the firm so that the feedback from the floor is generally impossible. For this reason CIM calls for a new type of industrial organisation and communication between the firms responsible for the design and the manufacturing job shop. The trend toward compatibility is a very important factor to be considered by smaller factories and larger firms. A technical centre can play a major role in advising and suggesting coordination when acting as an independent consultant. This task is not an easy one made more difficult by the rapid evolution of computing software and hardware. Efforts towards International Standardisation in this field are very slow. We all know about the difficulties experienced in implementing the famous MAP protocols, IGES structures, etc.

2.4 From a financial point of view the situation of an S.M.F. is quite different from that of a large concern. A large concern can decide to make a new investment to manufacture a new product, it can set up a new plant and have a dedicated team of engineers set apart from the daily production to conceive the new plant and to build it. In a smaller firm, the production cannot be interrupted, the move must be achieved with the same people, and financially the effort must be spread over a longer period up to integration. Therefore the key to successful implementation of CIM is stepwise implementation to ensure that every step pays for itself! [12]

2.5 Full and sincere cooperation of the people in the factory at all levels must be obtained. Everybody must be conscious of the fact that increase of quality and reduction of the cost price are the necessary conditions to stay competitive and to save jobs.

It is evident that persons will be transferred from the workshop floor toward higher quality jobs. During the first phase of the implementation procedure a large program of information and education must be initiated. The labor force has the right to know what their future is and must effectively be convinced that new technologies open new possibilities and create new jobs, but we must ensure that newly created jobs are kept in the region!

2.6 Successfully introducing CIM in a small or medium size factory entails far more than buying a computer for drafting and get acquainted with its use!

CIM calls for a new approach toward the manufacturing system as a whole. It means making the people conscious of implicit information to optimize practice, to cast it in a computer expert system and to make it flow back and forth between the different functions of the factory, so that it be available at the right moment at the most appropriate level for decision making.

3. TWO APPROACHES

In our work with Belgian S.M.F. we came to the conclusion that in setting up programs a bottom up procedure is definitely better suited for S.M.F. than a top down one.

When a good analysis of the workshop practice is made for the base of a generalised group technology system a large number of traditional pieces can be designed in a totally production oriented fashion right from the beginning of the design phase. Both procedures may be described in greater detail. [12]

3.1 Top down procedure

When the mnemonic CAD is used many people think of "Drafting with a Computer". [11][4]

Computer aided drafting is generally not economical. The real economic efficiency comes when routine design-computations are included and data banks are made available for searching for similar drawings, standards, part-catalogues and standard computing procedures. On the other hand a structural difficulty appears when trying to go from computer drafting toward computer aided manufacturing. These difficulties can be summarized as follows:

a) The computer sees geometrical entities as lines, surfaces, even volumes. The translation into manufacturing requires a transition to "technological entities" or say "manufacturable bodies".

b) One must be conscious of the amount of information missing which men add unconsciously when translating a drawing into a work piece, e.g. in a casting mould design, very often the roundings or chamfer are not dimensioned, inlet and air exhausts are roughly indicated, etc.

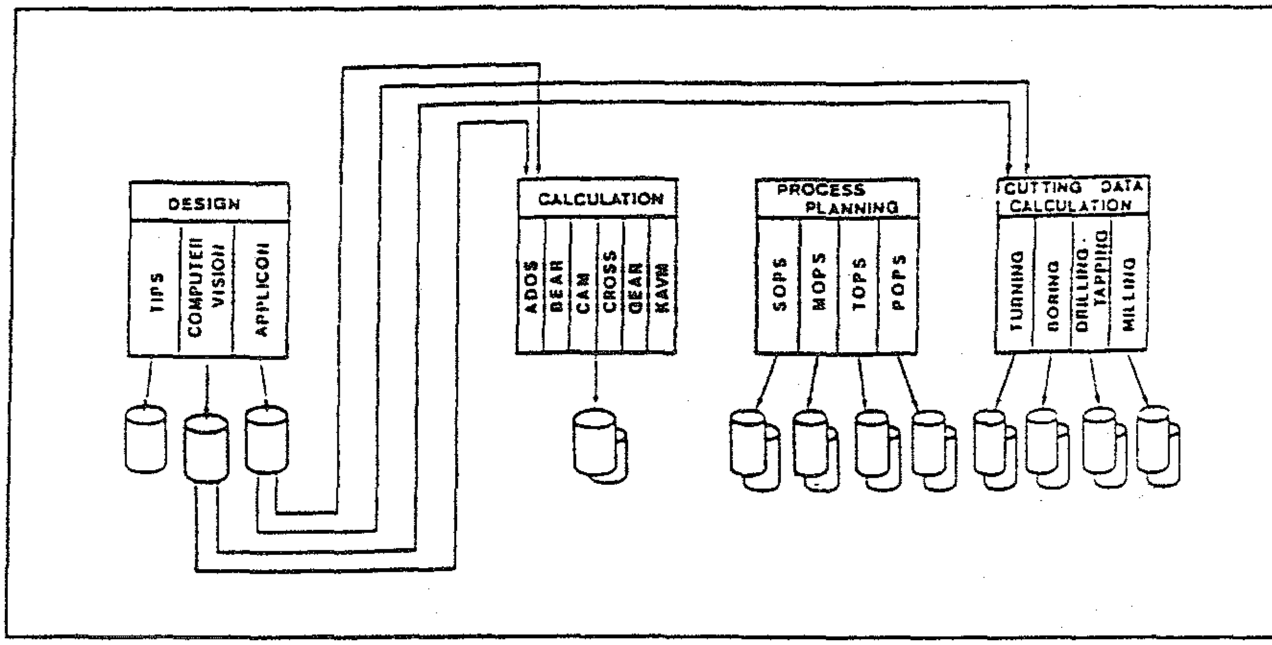


Fig. 1 A "traditional" top down layout

The workman knows and supplements the information. The computer however stops! Often things are drafted which cannot be machined or measured.

A top down approach generally leads to a very large number of branches in a branch and bound algorithm so that in most cases heuristics are used! Then the production foreman enjoys showing that he has a better solution than the computer!

3.2 The bottom up procedure

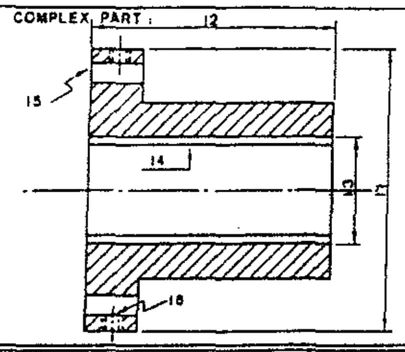
Let us than proceed the other way and start with the analysis of the work procedure in the workshop and progress up to the design room! [2]

A real expert system is designed reflecting the workshop expertise. In every case a variative or a generative approach can be used. The real key of the bottom up procedure is to reach the state where the design is made of manufacturable elements.

Prof. H. Optitz's Group technology system was a good attempt to achieve this goal to make families which possessed similar machining sequences, tooling, etc.

FAMILY : NUTS.

COMPLEX PART :



PROCESS INFLUENCING PARAMETERS.

l1 : Maximum diameter.
l2 : Part length.
l3 : Thread diameter.
l4 : Thread pitch.
l5 : Number of grooves.
l6 : Number of holes.

SEQUENCE PLANNING LOGIC			
Operation.	Machine	Set-up time	Operation time
SAWING	AMAD 02 If l1 < 30 WINOG 02 If l1 ≥ 30		
TURNING	search (l2 · l3)	10 min	0.2 · l2
THREADING	THRD 04	10 min	l3 / l4 · 3
MILLING	FRES 01	15 min	1.6 · l5
DRILLING	search (l1 · l6)	14 min	search (l1 · l6)

Fig. 2 A "a bottom up" layout

This was a fair success for rotational pieces, but for box type piece, milling etc. the approach was rather a failure.

Observing the way the thought processes of a person in the workshop proceeds, we observed that analysis of a work piece is done via "Technological Form Element".

This gave us the key to our system, which is now applied in a sufficient number of factories to confidently say that it works. Let us now give some examples.

4. EXAMPLES

4.1 MOPS - Machining Centre Operation Planning System

An S.M.F. was interested in computerizing the work preparation for a Machining Centre Operation. We proceeded in the bottom up fashion as follows: A precise enquiry was made at the factory concerning the usual procedures. Different approaches were compared and optimized, including tooling, set up and clamping operation sequence with the cooperation of the foremen and work preparation specialists. [3]

Great attention was given to identifying the discriminating element (e.g. dimension, shape or surface finish) a.o. leading to the choice of a specific production method or tooling. This information is not included in the top down design method. We discovered - what psychologists know - that the workman does not analyse lines but immediately grasps a structure, say technological elements to be machined a certain way, e.g. he sees a shaft to be turned: If a certain finish is required an additional grinding operation must be foreseen; or he sees a contour to be milled, as a whole or as a path according to its total extent vs the face milling cutter diameter; or he sees a hole to be drilled - or/and bored, reamed etc.

The fact which amazed us the most was that 90% of the box type pieces could be described by means of less than twenty "technological form elements", which may be characterised by an identification number, some manufacturing related parameter, dimensions, relational and position information.

The identification number refers to data bases, decision schemes, tooling, clamping etc., the choice of which depend upon characteristic parameters.

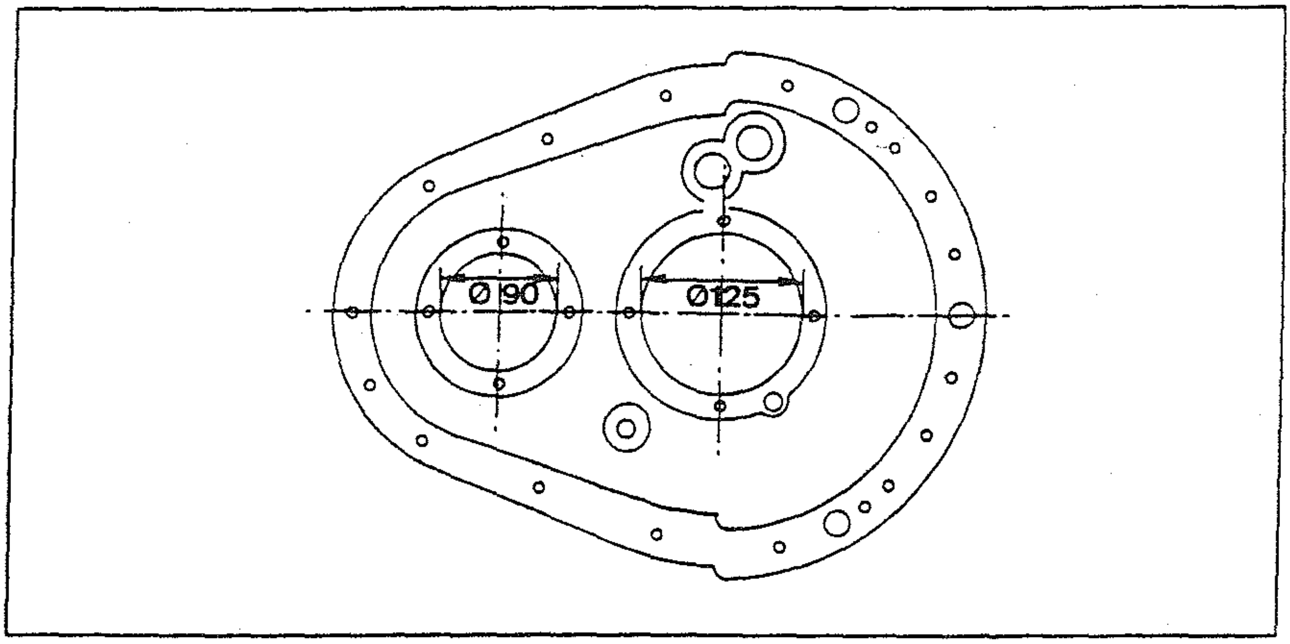


Fig. 3 Analysis of a Work piece into Technological Form Elements

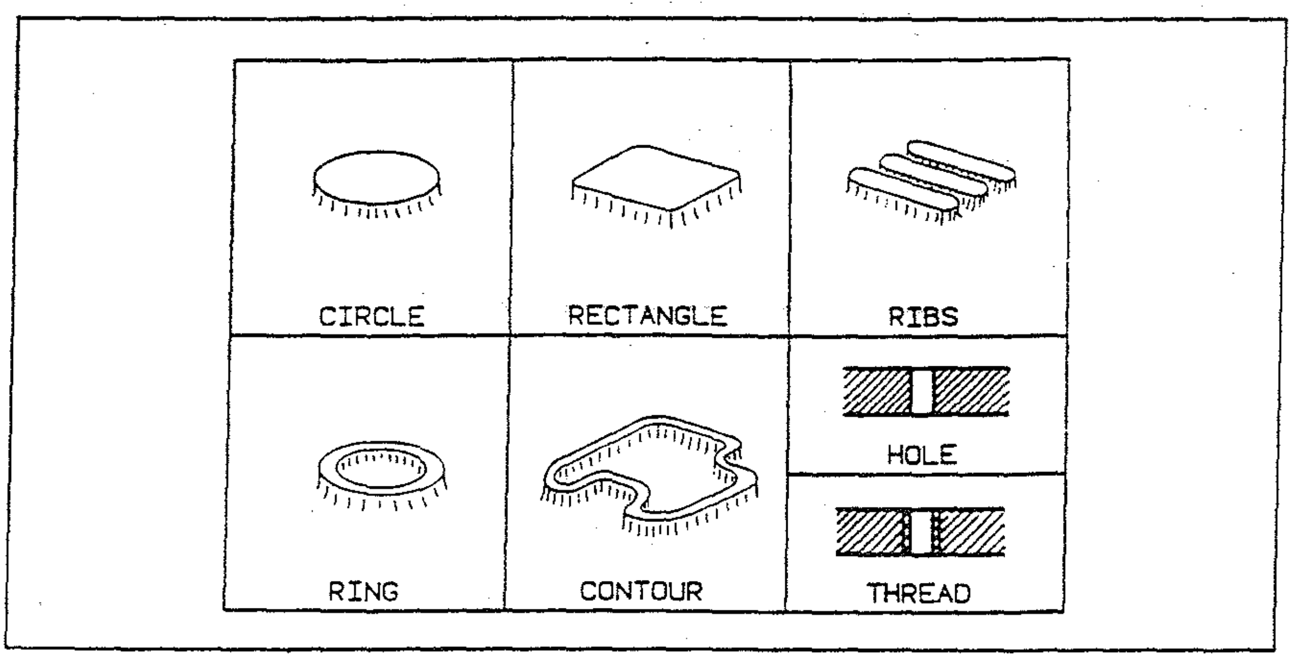


Fig. 4 Technological Form Elements

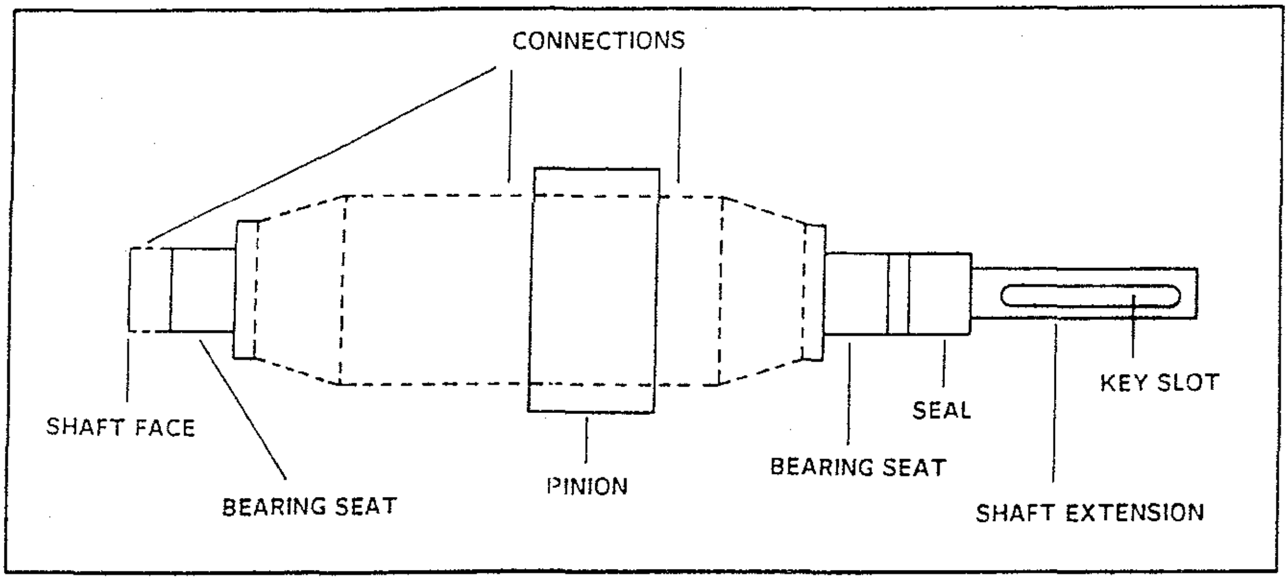


Fig. 5 Geometric model showing functional and connection parts. DOPS.

4.2 DOPS - Design of Pinion Shafts [9]

An example of nearly full integration from design to product is the DOPS program. It is an experimental fact that the integration can be more extensive and the program more efficient when the family of pieces is smaller.

A firm producing reduction gearboxes kept a family of 3000 different pinion types after standardisation. In order to respond to the requirements of the market more quickly they turned to flexible manufacturing. The pinion shaft design became the bottleneck especially when young inexperienced designers were assigned to the design.

Analysis of such a pinion shaft showed that there are only five functional requirements: shaft length, the two bearing seats and their location, the shaft extension with keyways, the pinion itself and its location.

The remaining parts are connecting elements, the outlet grooves, the shoulders and the tightness. All these elements are related to the manufacturing expertise of the firm.

The only items of input data given to the computer are the identification numbers and location of the five functional elements. The output of the computer program is the NC tape. As an intermediate output a drawing may be supplied for the purpose of checking.

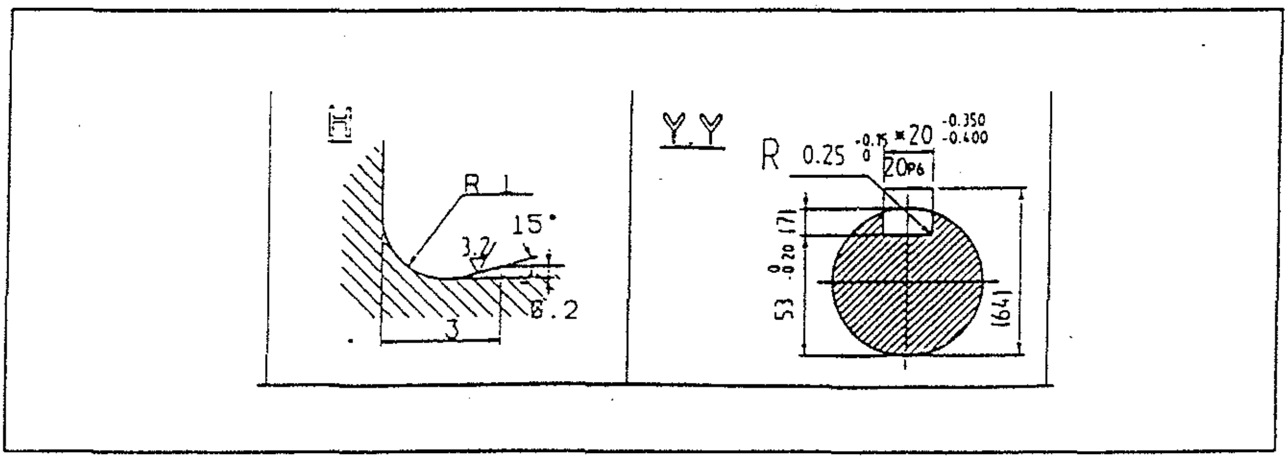


Fig. 6 DOPS Sticker

In order to achieve this the following data items are stored in the files which the computer consults directly:

The bearing manufacturer's information providing the dimension, the tolerances and the surface finish of the bearing seats.

The standards on gears providing all specifications required for the pinion, outer diameter, lengths plus all the dimensions of the roughing as well as the gear cutting data.

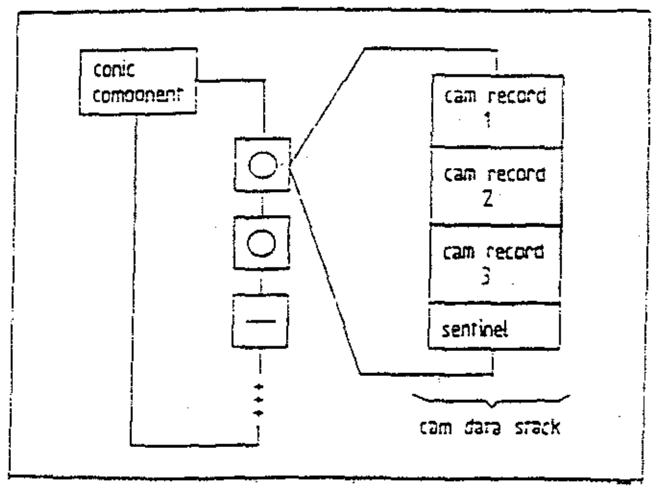


Fig. 7 Organisation of DOPS

The standard practice of the firm providing data for the shaft extension and keyways.

In all cases the dimensional specifications and manufacturing oriented data are provided.

The connecting parts are added automatically using firm specific decision schemes. The conical transitions have been standardised to 15°, 30° and 45°. The computer selects the most appropriate one using the specific decision scheme.

Shoulders and tool outlets are chosen according to the criteria used in the workshop. The most time consuming work in preparing the program was to enquire about the current practice and decision rules; simplifications were often suggested and agreed by the workshop concerned. Once a good "protocol" was established computer-integration is straightforward. The DOPS program is linked to a COMPACT II NC programming package which delivers a NC tape. The drawing is produced with all details and data as an aid to checking.

The profit opportunities for the firm are situated at different levels:

a) **At the design level:** The speed in responding to the market and a greater uniformity of product, avoiding the special features due to designer fantasy. The education of young designers, who previously needed some six months of practice to be fully capable, was reduced to two weeks.

b) **On the workshop floor:** No modifications need longer be made at the machine resulting in economy in tooling, a standard manufacturing procedure optimally using the full capacity of the production equipment and stability of quality.

c) **At the level of the overall organisation:** In respect of, planning, sequencing, even machine loading, significant progress can be made.

d) **At the marketing level:** Fast response, flexibility and quality.

4.3 COP - Cutting parameter Optimisation Programs [5][10]

Since this year the subject is being taught at the University. It can only be implemented when it is made "industry friendly", and integrates optimal workshop practice, e.g. characteristics such as stiffness, available power, rotational speeds, tooling data, work piece material, and cutting data.

In this sense COP goes much further than other commercial programs. It is an industry friendly computer program, which integrates workshop expertise within scientifically established models.

In order to suit S.M.F. a complete system must be introduced, integrating the particular workshop practice, the manufacturers catalogues, the machine data such as power and stiffness, available rotational velocities, the clamping, etc. All of it to be presented as a user friendly and flexible program, in which the change of a machine, the acquisition of new tools or materials can be introduced at minor cost and in a short period of time.

It can be seen that still much has to be done to standardize the presentation of technological data in computer friendly protocols!

The COP program has now been applied in seven S.M.F. in Belgium. The average overall gain amounts to a 40% decrease in production cost, and a definite increase in quality. At the present time a COP users group is serving the seven factories.

4.4 Additional Technological Programs

In response to industrial demand at the level of S.M.F., a series of programs for optimization work preparation and sequencing have been made available as follows:

SOPS	:	Sequencing optimisation planning system for organisational planning.
POPS	:	Punching operation planning system.
TOPS	:	Turning operation planning system.

All programs are now operational in factories. They all embody the same principle of a bottom up approach and the integration of specific workshop expertise. They have all been designed with a clear separation between general and firm specific parts so that the introduction of firm specific decision schemes and data are straight forward and easy. The implementation in a new firm requires less than two man days of work, provided the required data items are available. This however is often lacking: "People get things done ... but they do not know precisely what they do ... but it works". Extracting the workshop expertise and formalising it in an expert system and express it in terms of artificial intelligence is indeed a major challenge.

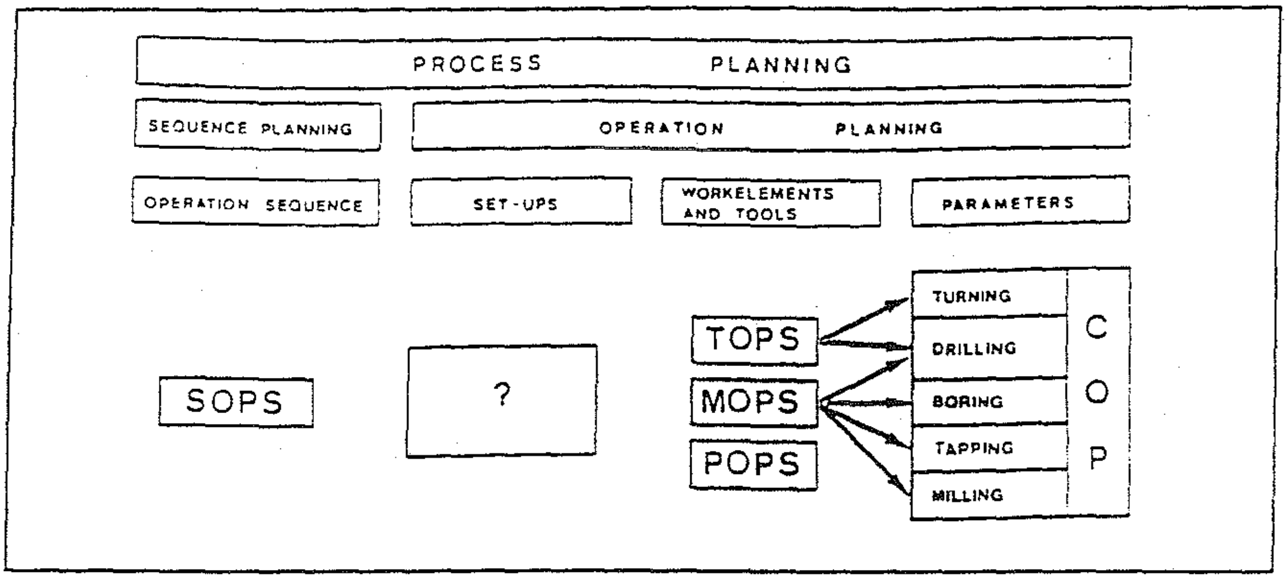


Fig 8 Layout of Process Planning

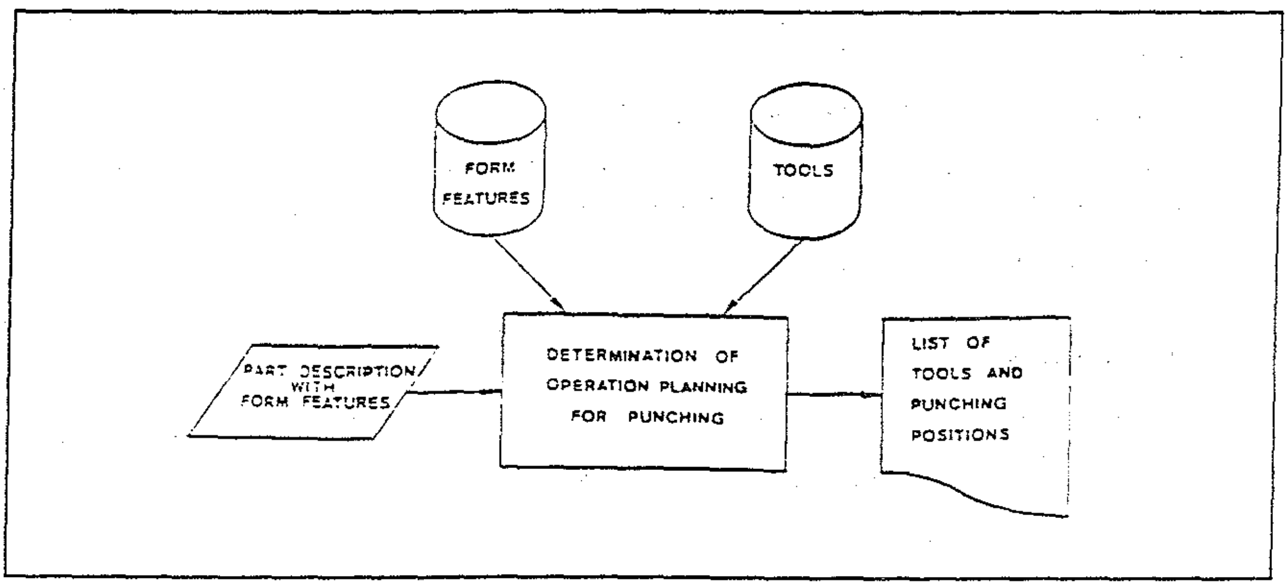


Fig. 9 Layout of SOPS

5. OPTIMIZED DESIGN AND MANUFACTURING PROGRAM

Another series of programs frequently required by S.M.F. are those where the emphasis lies in the optimisation of the design of specific families but in which the manufacturing preparation phase is limited to computer aided tool path control. As examples the CAM, and the GEAR programs are described.

5.1 CAM programs

Mechanical cams are still widely used machine elements in automatic machines such as textile machines, packaging machines, screw rolling machines and all kinds of food and agricultural machinery. Builders as well as users of textile machines and, packaging machines, a.o. are interested in optimizing cam design in order to increase the working speed.

In many older machines the design of cams generally consists of a series of circular arcs where transition is achieved by filing. Lack of continuity even of the third order between arc segments produces sudden changes of inertial forces and an infinite impulse. The follower jumps, causing vibration, noise and increased wear. The "CAM" program developed by CRIF provides a choice of different acceleration patterns and of follower types. It computes the shape of the contour as well as the velocity and acceleration peaks. When the designer has agreed upon an optimum contour, the paths of the milling cutter and of the grinding wheel centre are computed, taking into account possible undercutting or interferences.

Should a company require it, they can provide the post-processor of their production machine tool and the NC tape is immediately available. In certain cases even a direct DNC link has been made.

The real merit of the program is that it integrates standard and workshop practice in accessible data bases so that the inputs must only be given once, while the output of the CAD program is immediately provided as input to the NC processor.

5.2 The GEAR program

The GEAR program is one of the most cost effective programs. Using the usual input of power, torque, speed, a.o. the GEAR program provides the full computation of a gear couple from a strength point of view but also introduces all the data required by the different existing standards such, as ASME, ISO, DIN and others.

It also provides the workshop data, tooling, machine settings and other machining instructions.

One of the major benefits of this program is the availability of all standard data and specifications in a computer file or data bank.

Here again, when the machine files are available the NC tape can be produced directly.

5.3 Mould and die design

The problem of making dies and moulds becomes a crucial one for a group of small and medium size factories which up to now were successful in manually sculpturing shapes. Turning toward more effective methods has become a matter of survival.

A computerized procedure may probably be the answer. [1][7][8]

Even if the computerized definition of complex shapes is solved to a great extent, the integration of the technology in developing the mould shape is not straight forward.

Let us take the case of injection mould design. The goal is to directly produce the tool path of the different passes through the mould, given the a definition of the finished piece as sole input.

When this definition is given in computer compatible terms, one can immediately proceed to the mould design. When however a model or a drawing is given, the shape of the finished piece must be digitized and computerized by means of B-splines, cone surfaces or Bezier polynomials, each technique having its own specific domain.

However the description of the surface of the work piece is not the shape of the tool. One must introduce offsets, dimensions, clearance slopes, take into account nonhomogeneous shrinkage, look for the flow pattern, and material inlets, air exhaust, etc. Quite important cooperative work is being done in this field under the auspices of the European Brite or Esprit projects.

These programs are now under study. Using the description of the piece given by a computer definition, the aim is to generate the mould shape and hence the tool path for a milling operation. A data bank provides a list of the characteristics of the "auxiliary elements" such as inlets exhausts, to be used. Here again the full integration from design to production is aimed at.

6. COMPUTING AIDS

Scientists often polarize their attention to original solutions of particular problems. S.M.F. are generally better served with limited packages implemented upon small computers.

I refer to packages for computing mass, moment of inertia, centre of gravity, etc. which relieve the designer from repetitive calculations and provide a standard or firm specific procedure and avoid the "Monday morning errors".

An important package has been developed for the design of Mechanisms (KAVM). Besides the kinematic quantities the dynamic computations are also done. Another package is dedicated to the optimisation of machine tool spindles also taking the resonance frequencies into account (ADOS).

Many programs are designed to provide a friendly entry to larger commercial programs.

CONCLUSIONS

The integration of Manufacturing expertise in CAD/CAM for S.M.F. generally requires a bottom up process in which a major effort must be put into surveying the manufacturing expertise on the workshop floor to contain it in an expert system.

Considering the complexity of the problem, technological form elements must be recognized with their manufacturing specific parameters. In doing so the full cooperation of the personnel involved must be gained.

At the start a limited field must be chosen to gain maximum benefit. The structure of the program must be such to separate general procedures from firm specific ones to limit the cost of implementation by other firms. Modularity and compatibility are two major requirements allowing the stepwise introduction in S.M.F.

Experience has proved that the economic return of the appropriate implementation can hardly be overestimated but it is often difficult to financially quantify the benefit as a whole while so many savings are indirect and are not reflected in traditional accounting!

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