CHAPTER – 6
DIMENSIONAL TOLERANCES FOR CAST COMPONENTS

6.1 INTRODUCTION

Specifications are a set of conditions which qualify or disqualify a product. Tolerances indicate permissible deviations of manufactured parts from a specified quality attribute.

Tolerance are specified for chemical composition, dimensions and weight. It is desirable to specify tolerances in order to allow inexactness in the set-up or errors in chemical analysis.

Dimensional tolerance is one of the critical quality attributes of a metal casting, since its specification influences the casting process selection and determines whether machining will be required. The tolerances attainable for metal casting components depend partly on the process variables and partly on the nature of each dimension. The primary task of a designer is to specify minimum set of dimensions and tolerances for a cast component in order to allow its manufacture. Specification of dimensional tolerance in cast components is, therefore, mandatory in advance of manufacture. Dimensional tolerances should conform to the process capability.

The tolerances should be as small as possible from functional aspects of component and as large as possible to enable its economical manufacture. If they are too tight from manufacture stand point, then scrap rates will be excessive and result in higher costs. Therefore, an inappropriate tolerance not only affects the function, component life, cost of manufacture but also increases casting rejections and delivery date.

Specification control can be achieved to a great extent if the functional requirements and process capability are clearly established. Process capability is the amount of expected variation resulting from normal factors affecting the reproducibility of the process.

However, tolerance specification compatible to process capability is difficult to establish since it involves interaction of metal, design and process variables. The designer may not be cognizant of all process variable and so also the foundryman may not be cognizant of design variables which sometimes result in inappropriate specification. Therefore, the designer and
foundryman must interact to establish the tolerance which strikes a balance between process capability and functional requirements.

The specification control can be exercised to a great extent if an expert system is employed to identify functional as well as manufacture requirements to generate an economical tolerance. The system will just mimic the art of interacting designer and foundryman and arrive at an appropriate value in a way similar to them.

In this paper an approach for the specification of dimensional tolerance suitable for expert systems and its implementation in CASTEX are presented. The approach here is limited to the specification of dimensional tolerances only.

6.2 TOLERANCE SPECIFICATION PROBLEM

The tolerance specification problem can be defined as the selection of appropriate tolerance value for the critical dimensions of the component which should be as precise as possible, desirable and necessary to meet the intended function and service requirements and as large as practical, but economical from manufacturing standpoint.

The tolerance specification is essential in order to permit desirable clearance or interference between the mating parts in an assembly. The designers' job is to specify different types of fits and assembly. The designers' job is to specify different types of fits and tolerances limits which are compatible with function and process capability. The knowledge of function, intended service and component life requirements are necessary in order to specify the type of fit and tolerance limits. The knowledge of alloy and process variables, which affect the attainability of these requirements, is also essential.

The alloy variables include alloy composition, pouring temperature and alloy shrinkage. The process variables depend on the casting process selected. In case of investment castings the process variables include wax or plastic temperature, die temperature, mould or shell composition, back up sand, firing temperature, rate of cooling, position of part in investment tree and heat treatment, which all bear directly on tolerances required.
It is widely acknowledge that the designer and foundryman cannot independently exercise total control over the confluent variables on tolerance. However, the collaborative effort between them to gain an awareness of the existence and nature of the variables will alone result in specifying an economical tolerance value and making full utilization of process capability.

The design, alloy and process variables interact with each other and the dimensional variations are the net effect of the causal variations and make the tolerance specification increasingly complex. Therefore it is a formidable task to translate either net effect of the variables or each of them into appropriate tolerance value.

However, a series of tolerance grades as established by Steel Founders Society of America (SFSA), is a practical means of communicating the needed tolerances to the foundry and also expressing process capability of the various casting processes. The five tolerance grades T3 to T7 developed by SFSA are based on variable such as alloy, weight, dimension length, pattern material, moulding method, number of castings required, parting line etc., This helps reducing the complexity of the tolerance specification problem.

The process of selecting fits and tolerances from the functional requirements and comparing them with the practical tolerance grades of SFSA or can be expressed explicitly in the knowledge base of an expert system. The cost of manufacture can also be expressed in a database for comparison and selection of an economical tolerance value. The cost estimations is often fuzzy and often dependent on variables of cost of pattern, primary process, secondary process, quantity requirements. However the relative cost can be judged in advance of many active using fuzzy ranking. This tolerance specification is modeled and implemented in expert system CASTEX such that the system generates an economical tolerance grade by achieving a proper balance between function and process capability and cost.

3.0 APPROACHES TO MODELING THE TOLERANCE SPECIFICATION PROBLEM

An approach to tolerance specification of metal casting components for implementing through expert systems is not seriously contemplated so far. The expert system approach is certainly more flexible compared to algorithmic programs, for they are best suited only for
optimization of tolerances subjected to the constraints identified in a casting process. Expert systems approach can mimic the problem solving at an economical tolerance.

There are in fact two approaches for developing expert system for tolerance specification problem. First approach is to develop an expert system to interface with available algorithmic programs, for formulating the problem initially and later for interpreting the results of tolerance specification program. This kind of translation program will not do justice to AI principles because of limited flexibility offered by algorithmic programs during problem formulation stage. However, the second approach calls for developing a stand-alone expert system, which offers greater flexibility to incorporate the problem-solving behavior.

The tolerance specification problem is modeled and implemented in CASTEX in such a way that the tolerances specified will achieve a balance between intended function, process capability and cost of manufacture.

If the function of the casting permits assignment of tolerances which are normal with respect to process capability, then maximum economy can be achieved and not merely the lowest cost casting. If the tolerances chosen are not compatible with the process capability then it results in higher casting and also necessitate gauging and straightening operations. However, with the enhanced process capability such as additional cores, inspection and gauging operations changes in pattern and moulding sands, it is evident that a small additional investment can minimize the secondary processing expenses and results in lower cost of the casting for the level of function desired.

Therefore, most generous tolerances can be specified consistent with the proper functioning of the casting. However they should be compatible with the capability of the process selected and minimize the secondary operation costs and also final cost of casting.

6.4 MODEL OF TOLERANCE SPECIFICATION OF METAL CASTINGS

The problem of tolerance specification is modeled into four steps as follows (Fig 6.1)

1. Selection of finite set of tolerances consistent with function of the component.
2. Selection of an appropriate casting process and generating tolerances compatible to process capability.


4. Selection of the tolerance value, which achieves a balance between function and cost of manufacture.

The model is layered into four steps for favouring implementation flexibility. These steps are further explained as follows.

6.4.1 Selection of A Finite Set of Tolerances Consistent' With The Function of the Casting

Initially it is desirable to select the type of fit between the mating parts of the metal casting and then selecting two or three tolerance grades consistent with its function. Later the tolerance limits corresponding to the critical dimension can be obtained from the desirable standard, say ANSI or BS or BIS.

For example, consider the shaft mating the hub of a flywheel with a key. The functional requirements to be satisfied include (I) power transmitted, (ll) energy fluctuation, application (commercial or precision), flywheel size and construction (solid cast or sectional). The type of fits considered are locations interference or force fit with a key. The tolerance grades corresponding to these fits can be chosen from BIS-SP-13: 1963 or ANSI-84.1-R 1974.

The corresponding tolerance grades are H5-g5, H7-g6 and H8-g7. The tolerance limits for the diameter of the hub corresponding to these grades can be established from the tables. Let $F_1, F_2, F_3$ be the tolerance limits corresponding to these grades and correlate to the functions.

6.4.2 Selection of An Appropriate Casting Process Compatible With These Tolerances

The requirements for the process selection include size and shape, number of required castings and surface finish required.
After the process selection, the tolerance limits normal to the process capability are generated from the practical tolerance grades T3 to T7 as established by (SFSA). Let P1, P2, P3 be the tolerance limits which correspond to the basic dimensions of component depending upon process capabilities.

6.4.3 Cost Estimation of the Tolerances

If \( F_1 > P_1 \) it can be concluded that the casting tolerance are larger than process capability and the tolerance limit \( P_1 \) can be produced at normal cost.

If \( F_1 = P_1 \), i.e., the casting tolerances are more or less same as process capability. This necessitates full utilization of capability of the process i.e. small adjustments in pattern or moulds or cores and casting costs are said to be medium. On the other hand if \( F_1 < P_1 \), then the rejections will increase and simultaneously necessitate secondary operations such as grinding and machining. The casting costs are said to be premium.

The casting costs are classified as normal, medium and premium based on these methods. It is often cumbersome to estimate the specific cost of manufacture of these tolerances, for they vary from time to time, foundry to foundry and country to country. However, for the purpose of specification at design stage, it is adequate to compare the relative costs of manufacture. Therefore the casting costs are grouped using linguistic variables as enumerated earlier.

6.4.4 Selection of the Tolerance Limits to Achieve a Balance between Function and Cost of Manufacture

The tolerances selected on the basis of the function of the component can be graded as good and average in decreasing order of functional requirement. The tolerance grades can also be graded from the manufacture stand point as premium medium, normal in decreasing order of costs of manufacture. The tolerances are ranked using Table 6.1 and the tolerance with best rank is ultimately specified.
6.5 IMPLEMENTATION OF THE TOLERANCE SPECIFICATION APPROACH IN CASTEX

The steps involved in the tolerance specification model are implemented in CASTEX as follows:

6.5.1 Selection of A Finite Set of Tolerances Consistent with the Function of Casting

The CASTEX interactively acquires the functional requirements of the cast component and then selects a class of fit and a finite set of tolerance grades consistent with these requirements. For example in case of flywheel, the system acquires functional requirements such as power transmitted, speed, speed fluctuation, type of construction and application. The class of fit and corresponding tolerance grades are selected consistent with these requirements. For example, if the type of construction is solid, and power transmitted is <50 HP, and power speed transmitted is <6000 fpm, and power speed variation is moderate, and power application is I.C. Engine, and power engine type is stationary, then select – force fit.
Fig. 6.1: Assignment of Dimensional Tolerances
After selecting the class of fit, the system selects two tolerance grades from the database and establishes the tolerance limits corresponding to diameter of the hub. Let these tolerances \( F_1 \) and \( F_2 \) be graded as good or average on the basis of function.

3.5.2 Selection Of The Casting Process Compatible With These Tolerances

The expert system, CASTEX selects a process among the many casting process available which is compatible with these tolerance limits. The system finds a number of choices for casting the flywheel depending upon quantity requirements, size, weight and construction of flywheel.

If the process selection is already made at the alloy selection stage, then the system automatically starts generating tolerance limits, normal with the process capability. Let these tolerances be \( P_1 \) and \( P_2 \). If the difference between \( F_1 \) and \( F_2 \) and corresponding \( P_1 \) and \( P_2 \) is positive then \( P_1 \) and \( P_2 \) are chosen as tolerance values and the system attempts next step.

On the other hand, if the difference between \( F_1 \) and \( F_2 \) and corresponding \( P_1 \) and \( P_2 \) is negative but approaching zero, then the system makes suitable process changes in order to get a zero value of difference and finally establishes modified values of \( P_1 \) and \( P_2 \).

If difference is sufficiently large and negative the system suggests suitable modifications to process and also secondary processing to achieve the desirable tolerance limits.

6.5.3 Cost Estimation Of The Tolerances

The system estimates the costs of manufacture and classifies them into three categories. As explained in previous sections. The knowledge base stores the relative costs of all additional operations employed to control the tolerances. This kind of relative casting makes it easier to modify or change in case the costs change with time.

6.5.4 Selection Of Tolerance Limits

The tolerance values are graded from the stand point of function and cost of manufacture and ranked ultimately as explained in previous section. The tolerance limit with lowest rank is finally specified.