ABSTRACT

DESIGN FOR QUALITY MANUFACTURABILITY ANALYSIS FOR COMMON ASSEMBLY PROCESSES

by
Suriyanarayanan Ramachandra

The globalization of market economy has precipitated a dramatic increase in competition necessitating the need for higher quality products at lower cost in shorter time periods. Shorter life cycles and proliferation of products has made companies integrate all the phases of manufacturing to bring about a superior design. Design for Quality Manufacturability (DFQM) provides a technique to invoke manufacturing and assembly considerations while designing a product. The DFQM architecture identifies factors consisting of several variables that are influenced by certain error catalysts to cause one or more specific defects. A methodology is suggested to identify and quantify these error catalysts to be able to estimate the quality of the design.

Some of the assembly processes that are widely used are insertion, riveting, welding, fastening, press-fit, and snap-fit. A detailed study of each of these processes is done to analyze the techniques, capabilities, and limitations. Using the DFQM architecture defect classes and specific defects are identified and analyzed. A correlation matrix is formed to identify the processes that are associated with each specific defect. Cause-Effect analysis using Ishikawa diagrams provide a means of analyzing the characteristics of the relevant processes attributing to each specific defect. These characteristics are grouped to identify the error catalysts that influence the occurrence of the specific defect.

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by
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DESIGN FOR QUALITY MANUFACTURABILITY FOR COMMON ASSEMBLY PROCESSES

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This Thesis is dedicated to
my parents and brothers

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CHAPTER 1

INTRODUCTION

1.1 Product Quality

Product quality is the focal point of contemporary manufacturing industries all over the world. The globalization of market economy has brought a dramatic increase in the emphasis for product quality. Regardless of the corporate strategies, companies see quality as the only viable tool to increase and sustain market share. Such vigorous competition has given place to new techniques and methods for the purpose of enhancing quality standards. All these new technologies are dedicated to produce high quality products using minimum time and effort.

Manufacturers unlike before, have started to ponder about several facets of quality before the production stage. The concept of building the product for ease of manufacture and assembly started to evolve. The designers role in incorporating manufacture and assembly issues started gaining prominence. Quality experts identified that approximately 75% to 80% of the product cost is determined at the design stage, and recognized that the design stage is where the critical considerations should be made. In the early 80's several useful tools became available to help designers with their analysis. Design of products became accommodative to process variability, serviceability, testability, etc. All of the manufacturing problems in the quality perspective required to be visualized and solved in the design stage.

The proliferation of products in the market has remarkably reduced the life cycle of the product, necessitating the ability to introduce new products with superior quality in relatively shorter time period. All these developments have given rise to new buzz words - most notably " Simultaneous Engineering " or " Concurrent Engineering ". These approaches mean that all aspects of product design, manufacture, and marketing should be considered during the design phase by teams of individuals representing these various interests, so that all of the right decisions are made from the start. It became necessary to integrate manufacture and assembly along with the usual considerations of performance, appearance, etc. Several techniques for the implementation of concurrent engineering are available. One of the approaches to simultaneous engineering is Design for Manufacturability (DFM).

1.2 Design for Manufacturability

Design represents a progression over time from the abstract to the concrete. The activities involved in this progression can be divided into time sequence phases. As a part of each phase many problems must be resolved and technical, economical decisions made. These decisions generally require a great deal of information. The quality of the decisions often depends on the information. Changes in design happen due to inappropriate or lack of information when creating the initial design of the part. DFM addresses to this issue in manufacturing. The goals of DFM are to (i) minimize the design time, (ii) minimize the number of later changes, (iii) minimize the design to production transition time, (iv) attain the desired level of quality and reliability. To achieve these goals, DFM integrates the islands of operations into one by identifying design concepts that improve manufacturability, implementing these concepts into better design, and integrating process knowledge into design. Many DFM tools are available to accomplish the above mentioned objectives. However the only known technique that evaluates the quality of the manufactured part in the design stage is the Design for Quality Manufacturability (DFQM).

1.3 Design for Quality Manufacturability

DFQM analysis provides a means of relating the activities of product design and manufacturability analysis. This provides an efficient way to evaluate the design for manufacturing and consequently debugging the design before the actual commencement of production. Quality Manufacturability (QM) helps the companies spend lesser time and cost in fixing defects so as to improve their competitiveness.

The spectrum of quality defects by Das(1993), shown in Figure 1 illustrates the sources of quality problems. Several techniques and tools are available to determine the design and manufactured quality. The design to manufacturing interface is usually not formally addressed. The focus of DFQM is therefore on the design to manufacturing interface, and how it effects the manufactured quality.

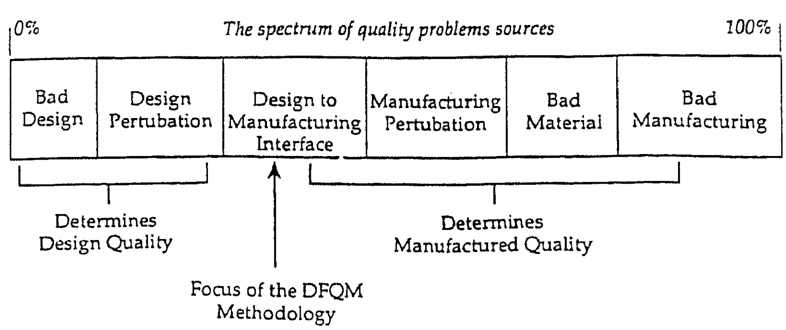


Figure 1.1 Spectrum of Quality Defects

1.4 Research Objective

The thesis forms part of a three year research which is currently under way. The research is funded by a partial grant from the National Science Foundation (NSF). Using the DFQM architecture, this thesis proceeds further by relating the assembly processes with quality defects. The research more specifically addresses to the assembly considerations of QM and probes the factors attributing to quality defects in different assembly processes.

1.5 Organization of the Thesis

The thesis consists of five chapters. The first chapter introduces the need for DFM, the concepts and its significance in modern manufacturing. Chapter two gives a survey of relevant literature pertaining to DFM, Design for Assembly (DFA), and current research in DFQM. Different assembly techniques and its capabilities, quality defect analysis are given in chapter three. Chapter four contains QM analysis of specific defects associated with different assembly processes. Conclusions and outline of further research capabilities is given in chapter five.

CHAPTER 2

LITERATURE SURVEY

2.1 Quality by Design

Traditional approaches to improving the quality of the product have been focused on either monitoring the process itself or inspecting the output of the process. Deming(1988) complains that manufacturers are too dependent on inspection as the road to quality, rather than problem solving methods which prevent low quality from occurring in the first place. In response to a call for quality prevention approaches several new methods have been reported in the literature.

The concept of "Quality by Design" (Deming 1988, Clausing and Simpson 1990) emphasizes on prevention rather than problem solving. Statistical process control techniques, Cause-Effect analysis (Ishikawa 1943) are used to identify potential source of quality problems. Huthwaite (1989), Yost (1987) evaluated the advantages of building quality in the design rather than developing it after the product has been produced.

2.2 Concurrent Engineering Approach

One of the major bottlenecks in the product realization process is the lack of systematic approach to the development of robust and reliable manufacturable products(NRC 1991). The product realization process which combines the activities of design, concurrent engineering, and customer needs interpretation. This called for a systems approach

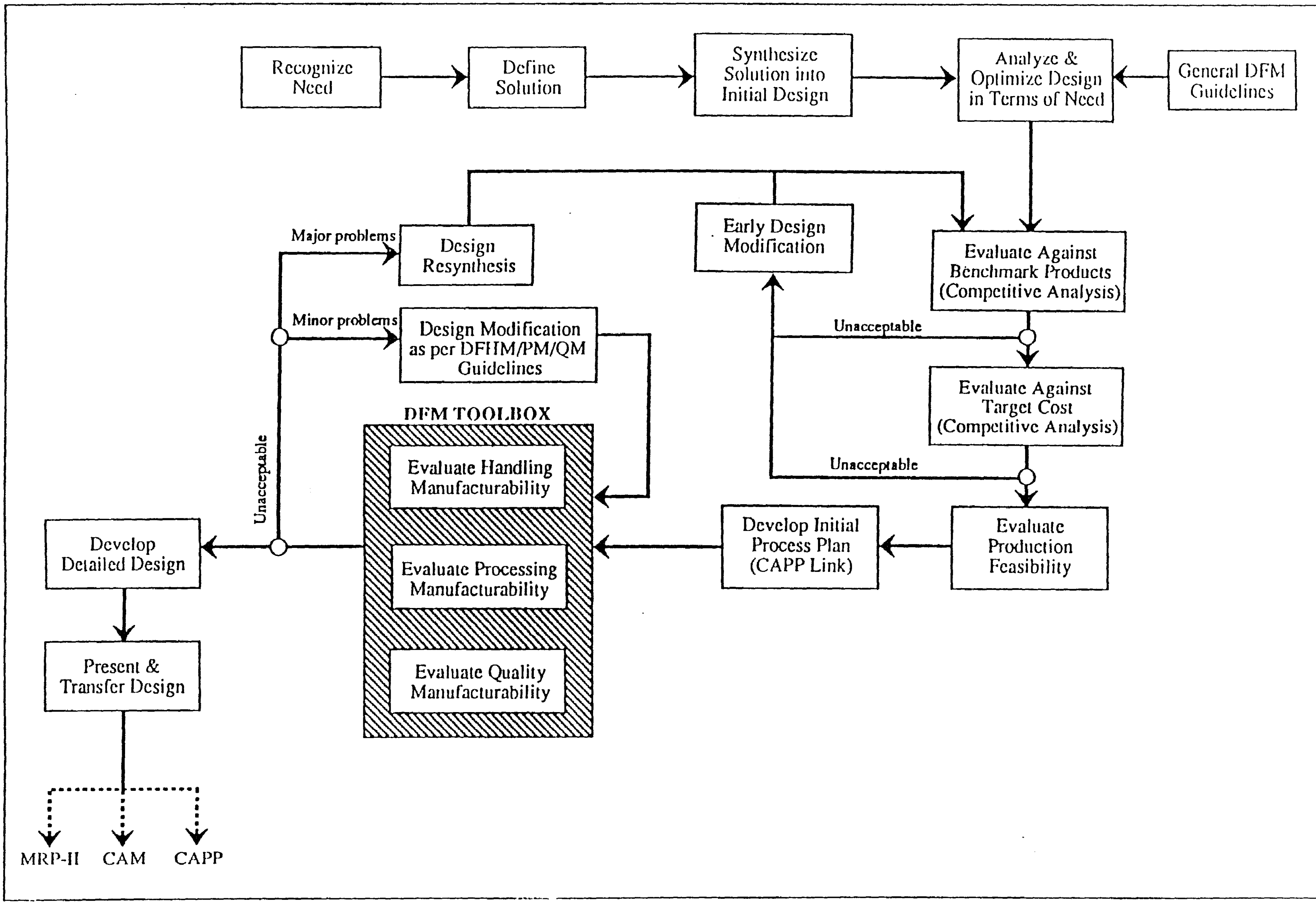


Figure 2.1 A Concurrent Engineering Approach to Product Design

towards product design integrating all the facets of the manufacturing process. This is baptized as the Concurrent Engineering Approach to Product Design (Das 1993).

Shigley (1963) proposed a model to improve the design by synthesizing and evaluating the design prior to production. The concurrent engineering approach is an extension of the Shigley model to enhance design techniques. This model(figure 2.1) includes "benchmark comparison" and "ability" of the design which are evaluated concurrently with its development. The Axiomatic approach proposed by Suh, Bell, and Gussard (1978) is based upon a hypothesis that there exists a small set of global principles, or axioms which can be applied to decisions made throughout the synthesis of manufacturing system including evaluation of a design decision leading to a good design. Taguchi (1980) suggested robust design principles which can accommodate for process and system variability in the design and used statistical design of experience and orthogonal arrays to evaluate the design. Some of the other techniques that are capable of evaluating the design are the Designers Toolkit, and Failure Mode and Effect Analysis.

2.3 Design for Assembly Techniques

Several techniques are available to evaluate the design for manufacturability. The more well known among the techniques are the Boothroyd and Dewhurst approach(1983), the Hitachi Assemblability Evaluation Method(1983), and the Variation Simulation Analysis(1989). Boothroyd and Dewhurst(1983) computed the design efficiency by evaluating the orienting, handling, and assembly difficulty. The Hitachi Assemblability(1983) though similar to the Boothroyd and Dewhurst method(1983),

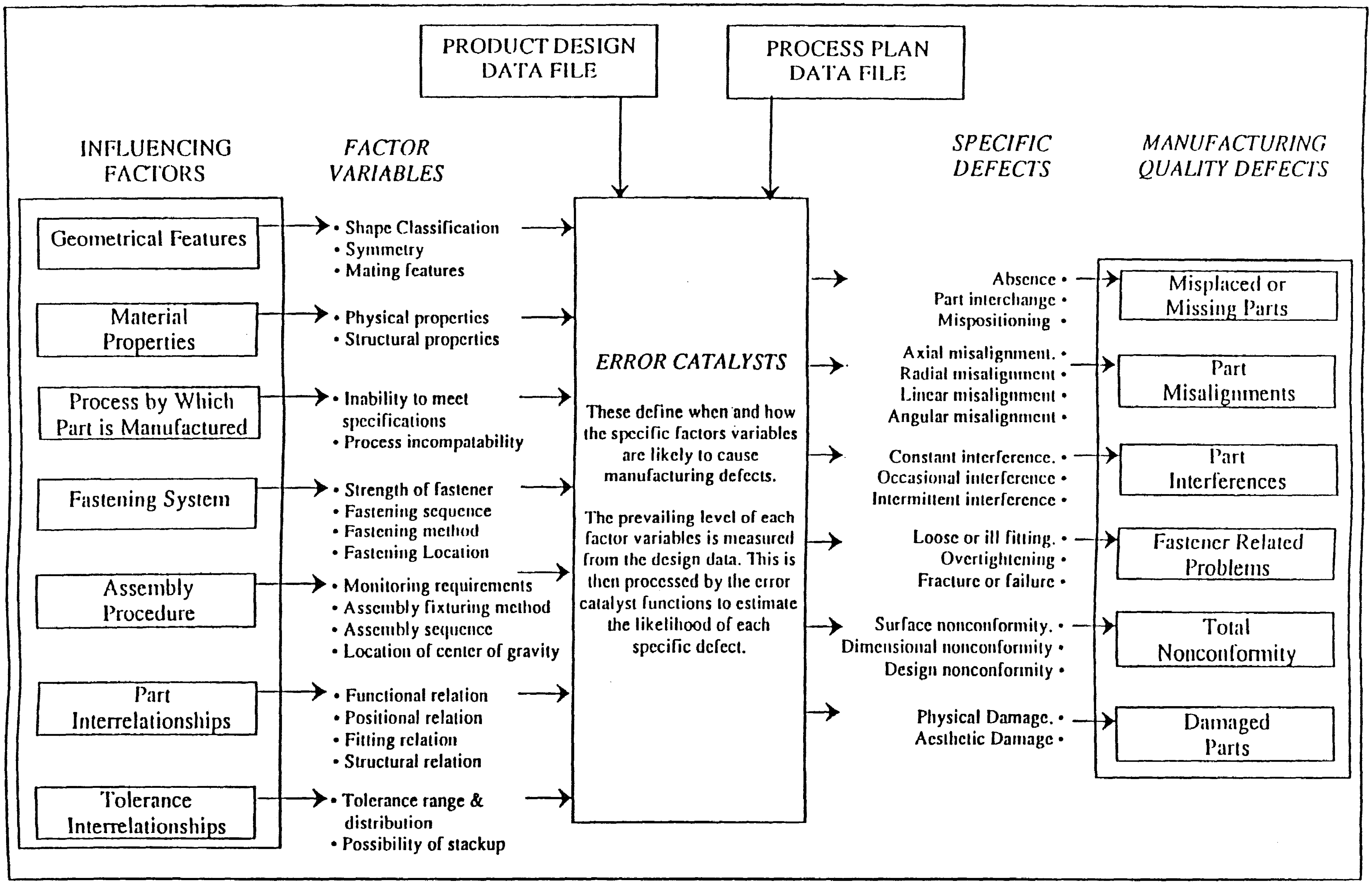


Figure 2.2 DFQM Architecture

focuses on the cost involved in handling and assembly of the parts and identifies areas of focus for efficient product assembly. The Variation Simulation Analysis (1989) by Westinghouse Corporation, uses simulation techniques to analyze complex assemblies prior to their prototype production and enable designers make changes in the design, and study the assembly process variables. Malek (1985) in his study on the automatic assembly process, analyzes the repeatability of the executing organ and proposes a model to maximize the production rate of the assembly process. Tolerance interrelationships and their distribution is one of the key factors that often influences the quality of the manufactured and assembled product. A model for optimizing the cost and functionality of the components (Malek and Asadathorn 1992) focuses on several aspects of tolerance to improve the quality of the product.

2.4 DFQM Methodology

Das (1993) in his DFQM model investigates the relationship between the design of a product and the difficulty associated with its manufacture. The model estimates the quality of design from the manufactured quality perspective. This methodology identifies quality defects that are commonly existent in assembled products and probes the factors and variables that influence the occurrence of one or more defects. This enables to accomplish a reverse Cause-Effect analysis by predicting the effect after identifying the causes. The general structure(Prasad 1992) of this methodology is depicted in the DFQM architecture(figure 2.2).

2.5 Summary

The proposed methodology for evaluating a design for deficiency to determine its quality manufacturability by Das(1993) focuses on the design-manufacturing interface. This methodology has to be developed further to be able to formulate a model that can evaluate the QM of a design. The research leading to the documentation of this thesis goes a step further from the basic DFQM structure. It analyzes the capabilities, limitations, and techniques of different assembly processes and correlates it to one or more specific defects. The analysis provides a means to identify a set of error catalysts associated with these processes that influence the occurrence of quality defects.

CHAPTER 3

ASSEMBLY PROCESS AND DEFECT ANALYSIS

3.1 Common Assembly Processes

3.1.1 Assembly Processes

Some of the most common assembly processes used in the industry are : insertion, riveting, welding, fastening, press-fit, and snap-fit. These processes are used to secure parts together with varying strengths to form the final product. The conformance of the assembled product to the design is dependent on the techniques, capabilities, and limitations of the assembly process used. A detailed study of each of these processes is done to study their specific characteristics which can be related to one or more quality defects in the assembled product.

3.1.2 Insertion

Insertion is a physical process where a part is inserted into a hollow envelope in a predefined fit pattern. The workpiece that consists of the hollow space is called the 'work' and the inserted piece is called the 'part'. The parts that are inserted are not formally fastened to the work and generally confined to the constrained space of the work envelope by virtue of the assembly orientation or due to the action of some holding mechanism.

One of the most important factors that effect the success of inserted assemblies are the conformance of the part and the work to the stipulated geometrical and dimensional the assembly. However it is not uncommon to find defective assemblies despite the fact that the parts being assembled are within the design specifications. The repeatability of the executing organ could cause this to happen. In the process of inserting a part in to the work, two outcomes (Malek 1985) are possible : a success or a failure. In the case of a success, however wedging may occur(Malek 1985). In figure 3.1b and 3.1c where wedging occurs, a proper passive compliance system facilitates the assembly completion,

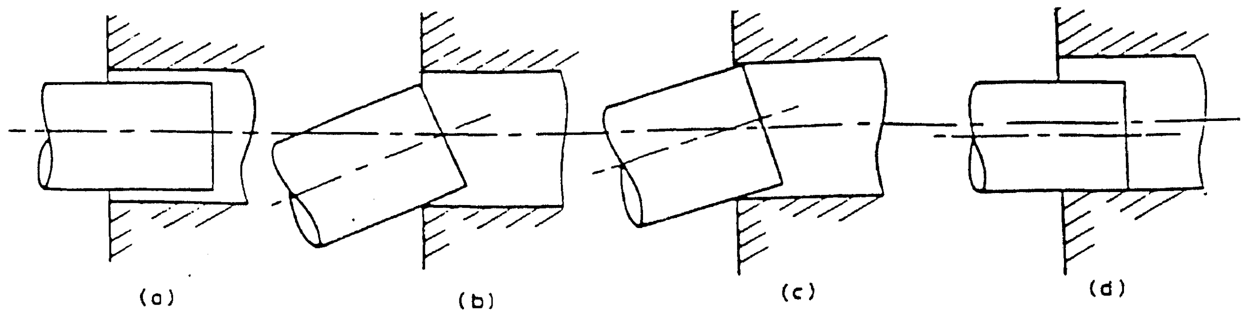


Figure 3.1 Different possibilities in insertion

increasing the process productivity. Force feedback may also be used to overcome wedging and jamming.

The factors that effect the fitting relationship in the insertion process are the clearance between the part and the work, geometrical homogeneity, compatibility of material properties, geometrical/dimensional conformance, tolerance interrelationships, and force feedback. The load distribution in insertion is generally of the dead load type, while the stress analysis is performed for the tensile, bending and shearing stresses. The direction of the load is dependent on the orientation of the assembly and the method of insertion. When the assembly involves insertion of multiple components inside the work envelope, stress analysis for compression is conducted in addition to the others mentioned above. In automated assemblies where robots are used in the insertion process, the repeatability of the robot is a crucial factor determining the success/failure of the assembly(Malek 1985).

3.1.3 Riveting

Rivets are used extensively for joining and fastening metal sheets when brazing, welding or other locking techniques will not provide a satisfactory joint. Rivets are easy to install and make an almost instantaneous tight, permanent joint. Rivets though seldom, are even used to join fabrics, plastics, leather, and wood to metal. The major types of extensively used rivets include the standard type and pop rivets. Standard rivets must be driven using a bucking bar, whereas pop rivets have a self heading capability and may be installed where it is impossible to use a bucking bar.

Standard rivets: These are like threadless bolt which is slipped through a hole drilled in the materials that are being put together. When struck with a rivet hammer the shank is flattened into a mushroom-like head that keeps the material from coming apart. For thin or lightweight materials, a washer is slipped over the shank for extra holding power. Rivets are classified by lengths, diameter, and their head shape and size.

Pop or blind rivets: These can be used where there is limited access or no access to the reverse side of the material. The rivet is made up of two parts, the mandrel and the rivet body. Tow basic designs of pop rivets are the closed-end and open-end. The high degree of radial expansion in closed-end rivets provide excellent hole filling characteristics. There are special rivets with extra large flanges for large holes in soft materials, counter sunk rivets for flush surfaces, threaded rivets for setting threaded holes in materials, and washer-type rivets that provide back-up plates for soft materials.

Rivets are generally subjected to the following forces: (i) tension, (ii) shear, (iii) combined tension and shear. The tensile strength of a driven rivet depends on the mechanical properties of the rivet material before driving and driving temperature. Experiments show that driving generally increases rivet strength. Strain hardening of cold driven rivets also results in increased strength. Most tension tests of driven rivets show a tendency to decrease in strength as the grip length is increased, since the driving energy per unit volume is decreased.

Single shear as compared to double shear loading condition results in a slight decrease in strength. This is caused by the out of plane forces and secondary stresses on the rivet due to the inherent eccentricity of the applied load. In most single shear test joints, the rivet is not subjected to a pure shear load condition. Furthermore, since driving a rivet increases its tensile and shear strength.

As the loading condition changes from pure tension to pure shear, a significant decrease in deformation capacity is observed. It should be noted that the character of the fracture and the deformation capacity changes substantially as the loading condition changes from shear to combined shear and tension and finally to tension.

3.1.4 Welding

Welding is defined as a process of joining metallic or nonmetallic materials in a relatively small area by heating the area to the welding temperature. Welds may be made by applying/not applying, with/without filler material. Most welding processes require the addition of heat to the weld area in order to bring the contact site to molten state. The molten areas of the weld joint then flow together, forming a single unit after they cool.

The junction of the two members are called as joints. There are five basic types of joints: butt joint, corner joint, edge joint, lap joint, and tap joint. These are shown in figure 3.2. There are many different types of welds such as fillet weld, groove weld, flange weld, plug weld, slot weld, seam weld, surface weld, and backing weld. There are four basic welding positions: flat, horizontal, vertical, and overhead. There are approximately 50 different distinct welding processes, subdivided into seven groups. They are arc welding, brazing, oxyfuel gas welding, resistance welding, solid-state welding, soldering, and other welding processes.

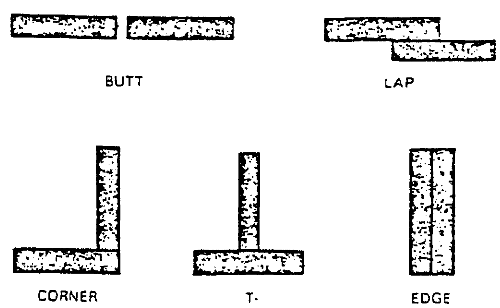


Figure 3.2 Types of welded joints

The basic variables that effect the quality of weld joints are the following :

(i) the welding process and its variations, (ii) the method of applying the process, (iii) the base metal type, specification, or composition, (iv) the base metal geometry,

(v) the base metal need for preheat or post heat, (vi) the welding position, (vii) the filler material and other materials, (viii) the joint type, (ix) electrical or operational parameters, and (x) the welding technique.

The most economical and successful solutions to a design requirement will be accomplished if the designer takes into consideration the type of loading, allowable working stresses, and the capability of the welding process to determine the service standards of the product.

Stress analysis on welded joints must include static loading and dynamic loads including impact and fatigue. The assembly must support its own weight, the dead loads, and the superimposed loads and forces produced by all service conditions including all live loads and forces, centrifugal or accelerating/decelerating action, transmission of loads, and loads due to thermal stresses. It is a common practice to classify the type of loads and from these to determine the types of stresses in the structure. The five basic types of loads on the weldments or as follows: tensile load, compression load(short and long sections), bending load, torsion load, and shear loads.

It is important to consider the weldments as monolithic structures while evaluating the loads and stresses, i.e. load imposed on one particular piece is transmitted through the weld joints to other pieces of weldment. It is also imperative to evaluate stress concentrations. A stress concentration is a point within the structure at which the stresses will be more concentrated than in the remaining cross-sectional area.

Besides the load and stress factors, the weldment's appropriate service temperature limits, resistance to corrosion, and abrasion should also be considered in the design stage to build a rigid welded assembly.

3.1.5 Fastening

Fastening is a physical process where different parts are put together using fastening elements. The most commonly used fastening elements where the parts may be taken apart later are screws, bolts, studs, and nuts. Figure 3.3 illustrates the common type of fastening elements. The most common classification of screws are the machine screws, cap screws, and set screws. Machine screws are small screws that are used in tapped holes with matching threads. Capscrews are larger size screws used for heavier work and come with nuts. These pass through the clearance hole in one piece and screw into a tapped hole in the other as the head draws the parts together. Setscrews screw into a tapped hole in an outer part, often a hub, and bear with their points against an inner part, usually a shaft. Setscrews hold two parts in a relative position by having the point set against the inner part. The point shape is the most important feature because it determines the holding quality of the setscrews. Bolts pass through the clearance holes in two parts and draws them together by means of a nut screwed on the threaded end. Studs are used when through bolts are not suitable for parts that must be removed frequently. Besides this there are many other forms of threaded fasteners that serve special purposes.

Mechanically fastened joints are conventionally classified according to the type of forces to which the fastening element is subjected. These classes are (i)shear, (ii)tension, (iii)combined tension and shear. Under category (i) the fasteners are loaded either in axial or eccentric shear. If the line of action of the applied load passes through the centroid of the fasteners group, then the fasteners are loaded in axial shear. In eccentric shear the shear force does not pass through the centroid. This results in an additional torsional moment on the fastener group that increases the fastener shear stresses. Most

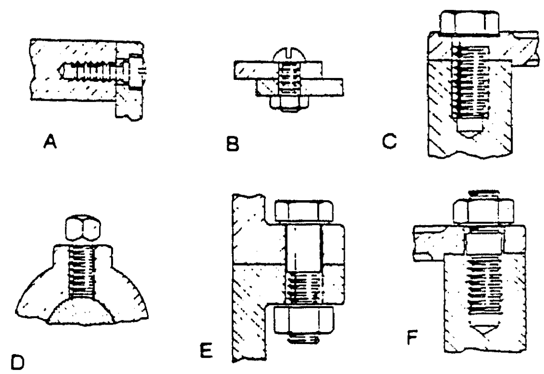


Figure 3.3 Common types of fasteners

often fasteners are subjected to the combined action of tension and shear. This is common in connections that are required to transmit moments to ensure continuous structural action. The amount of continuity depends upon the ability of the connection to resist moments. Moment connections may produce conditions where the upper fasteners are being loaded in shear by the vertical reaction and loaded in tension by the end moment.

Many structural members may be subjected to frequently repeated cyclical loads. Members and connections under such conditions may eventually fail from fatigue or stable crack growth, even though the maximum applied stress is less than the yield stress. In general fatigue failures occur when the nominal cycle stress in the member is much lower than the elastic limit. Because of this, fatigue cracks are difficult to detect until substantial crack growth has occurred. Fatigue crack growth usually starts on the surface of a point of stress concentration such as a hole, a notch, a sharp fillet, etc.

Since the behavior of a fastener subjected to an axial load is governed by the performance of its threaded part, load elongation characteristics are very important. Due to high stress level in the threaded part of an installed fastener, some relaxation is bound to occur. Upon completion of the torque a significant drop in load is observed. This is believed to result from the elastic recovery which takes place when the wrench is removed. Creep and yielding in the bolt due to high stress level of the root of the threads might result in a minor relaxation as well.

Under certain conditions, corrosive environments may be detrimental to the functionality and the serviceability of fasteners. To prevent this galvanizing the fastening site is used. If the fastener tension is induced by turning the nut against the gripped materials, unlubricated galvanized fasteners experience a greater reduction in tension as compared with torqued ungalvanized ones. The frictional resistance on the threads of the galvanized fasteners cause a considerable decrease in ductility. Washers are used to protect the outer surface of the connected material from damage and to assist in maintaining a higher clamping force.

3.1.6 Press-Fit

Press-fits are a subset of the insertion process discussed earlier. The distinguishing element is the tolerance distribution between the part and the work. Typically in press-fits the work has a positive unilateral tolerance while the part has a negative unilateral tolerance about the same mean diameter of the hollow envelope. Parts to be mated are pressed in using a stipulated amount of force. The permissible or acceptable variation in the dimensions of the parts allows the leeway for ramming. However strict conformance to geometric requirements is necessary for successful press-fits.

The strength of press-fits are mostly derived from the friction as a result of the difference in tolerances. When two or more parts are combined, the effect of their deviation from the nominal size becomes more pronounced. Several methods exist for evaluating the combine tolerances, such as linear methods, Taylor series approximation, approximation by numerical integration, (Malek1992) and the Monte Carlo simulation.

Material properties play a crucial role in press-fits. Mating parts with low coefficient of friction have poor retention capabilities and are unfit for press-fit assemblies. Even in materials with acceptable coefficients of friction, higher surface finish is undesirable. The press-fit components are continuously under stress arising from the assembly process. Therefore over a period of time, stress relaxation and creep may cause a press-fit to fail. The load configuration on press-fit assemblies are usually dead load. Depending upon the orientation and geometry, press-fits may be subject to impact loading also. The part is under a compression load while the work is subjected to tensile stress during the assembly processes. Considerable relaxation is observed due to elastic recovery after the press-in force is released. Cylindrical press-fits perform very well even under torsional effects. The advantages of a press-fit assembly is that these are simple geometry requiring no stress concentration grooves or notches, and the requirement of high press-out force to disassemble the part.

3.1.7 Snap-Fit

Snap-fit is one of the assembly processes that is capable of producing both detachable and permanent joints. This unique attribute of snap-fits has augmented its application. Besides being simple and inexpensive snap-fits have superior assembly quality. A successful snap-fit design is dependent on a set of rules governing shapes, dimensions, materials, and the interaction between mating parts. Snap-fits can be characterized by the geometry of its spring component. The spring component is the mating part with undercut features which when extended, passes over the interference to be in a secure position. The most common snaps are (i) the cantilever type, (ii) the hollow cylinder type, and (iii) the distortion type. Figure 3.4 illustrates these snaps. The choice of material, geometric stability and strength are different for each type.

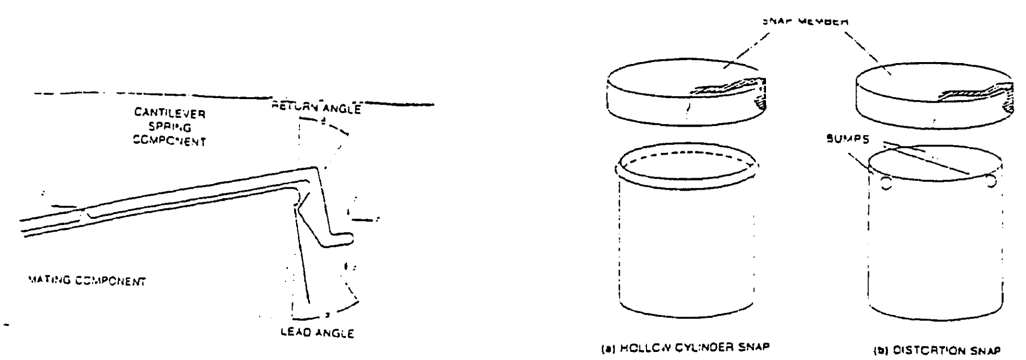


Figure 3.4 Snap-Fit types

The strength of the snap-fit comes from mechanical interlocking as well as from friction. Rigid interlocking can make pull-out strength many fold larger than the snap-in force. Snap-fits are often misconceived as unrigid contacts since they are as regarded as vibration prone. On the contrary, snap-fits are vibration proof because the assembled parts are in a low potential energy state. Proper design of spring and interference will provide rigid mechanical interlocking, and the friction between the mating parts influence the snap-in and snap-out forces. Many snap-fits are designed with locking lead and return angles to facilitate assembly and disassembly. However the kinematics of lead angles are complicated by the deflection of parts under load. Most lead angles calculated from unloaded configurations change upon loading. If a snap with locking lead or return angles deflect in such a way as to increase the angles, the snap is a true locking snap. Another most crucial factor determining the success of snap-fits is the choice of materials. Snap-fits are so widely used in the plastics industry because plastics can tolerate a large strain at their elastic limits, and because they have low elastic moduli. Materials such as cast iron, glass, that have poor resilience are not suitable for use in the spring component for a snap.

Of the three snap-fit types, the hollow cylinder snap is the strongest and has the most stable geometry. Hollow cylinder type snaps experience circumferential tension which demands an exceptionally low modulus of elasticity and a high elastic limit. The distortion type snaps in any shape that is deformed or deflected to pass over the interference. This causes the snapping member to experience hoop stresses due to expansion. Distortion snap member usually are subject to stress only due to bending. Cantilever snaps are less stable than hollow cylinder and distortion snaps, especially in torsion and impact. For this reason snapping members in the cantilever snaps are made of hard materials.

3.2 Defect Analysis

3.2.1 Definitions

The general structure of the DFQM methodology proposed by Das(1993), creates a generic process by which the relationship between the design of a product and the difficulty associated with its manufacture is established. This structure is a sort of reverse cause-effect analysis. That is the cause are identified foremost and then the effects are predicted. Therefore when an undesirable effect is got, then the cause is appropriately removed. The manufactured quality of a product is perceived as aggregate representation of several classes of defects that are commonly seen in assembled products. The occurrence of these defects is known to be influenced by several factors or characteristics that are inherent in the product's design. While the complete lists of the classes of defects is quite large a shorter list of the most common assembly defects are identified in the DFQM architecture(Das1993). In support of the proposed structure the following definitions are introduced :

- Class of Defects - A general category of defects commonly found in assembled products. These defects must be related to the processes via which the product is assembled or manufactured.
- Specific Defects - A more detailed description of particular defects within each defect class. Typically, specific defects belonging to the same class will be similar in their overall effect on the quality of the product, and their general nature. They will differ in terms of what causes them, and their specific orientations.

- Influencing Factor - A feature of the design or assembly process which can lead to one or more of the above defects. Factors may relate to the physical attributes of the design, or the manufacturing process.
- Factor Variables - A detailed variable that is representative of a particular facet of a influencing factor class. Typically, each factor variable should be related to one or more specific defects.

3.2.2 Standard Class of Quality Defects

Misplaced or Missing Parts : This is one of the most common defects occurring in assembly. Specific defects in this class or part absence, interchange, or mispositioning. Figure 3.5 illustrates examples of this class of defects. It is one of the most common defects when fasteners, parts, locking mechanisms, lining material, gaskets, etc. are specified in the design. When the defects of this class are not detected during assembly they could severely effect the quality of the product.

Part Misalignments : Misalignment is defined as the defect resulting when two related parts are not in alignment with each other, either functionally or aesthetically, as intended in the design. Misalignment is probably the most easily noticeable external defect fin assembled products. The specific defects in this class are; (i) axial misalignment which represents any displacement along the Y and Z axes, (ii) angular misalignment which represents any angular distortion along the Y and Z axes, (iii) linear misalignment which represents any displacement along the X axis, and (iv) radial misalignment which represents any angular distortion along the X axis. Figure 3.6 illustrates these misalignments.

Part Interferences : Interferences are caused whenever there is an unplanned contact between two moving parts. Interferences have a significant impact on both the functional performance of a product and its perceived quality. On the basis of the frequency at which the interference occurs, three types of specific defects can be identified, they are : (i) constant interference which is encountered during the entire motion cycle, (ii) random or occasional interference which is encountered once in a while, and (iii) intermittent, periodic, or cyclic interference which is encountered at fixed intervals in the motion cycle. Figure 3.7 illustrates the interferences.

Fastener Related Defects : This class of defects is dependent on the characteristics, features and type of fastener used in the assembly. The three most common types of fasteners are threaded, riveted, and adhesive or liquid fasteners. Figure 3.8 illustrates the above defects.

Design Nonconformity : In an assembled product two or more components are usually brought together. This results in a physical mating relationship between the components. For example, one part will nest in another, or one part will slide on another. Often some of these relationships are strictly defined, and even the smallest variation could lead to nonconformity which adversely effect the product quality. The specific defects in this class are surface non conformity, and dimensional nonconformity which are illustrated in figure 3.9.

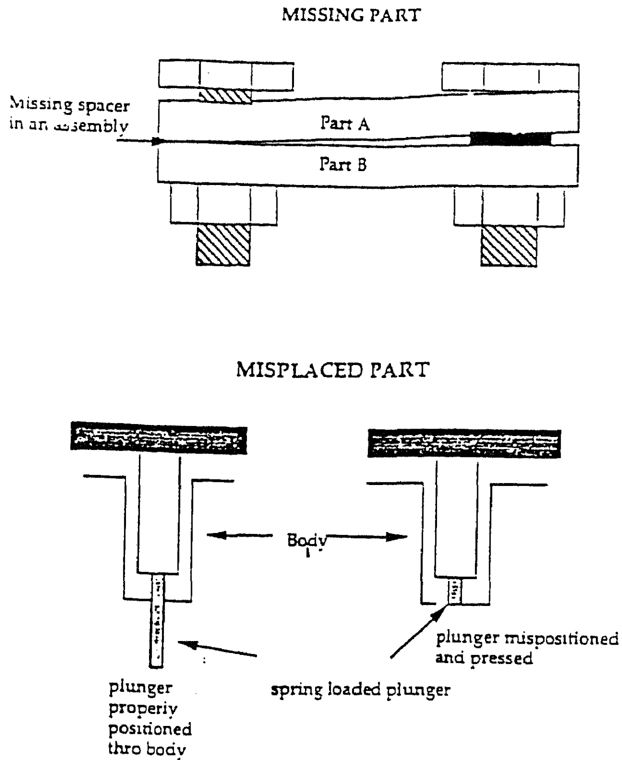


Figure 3.5 Misplaced or Missing Parts

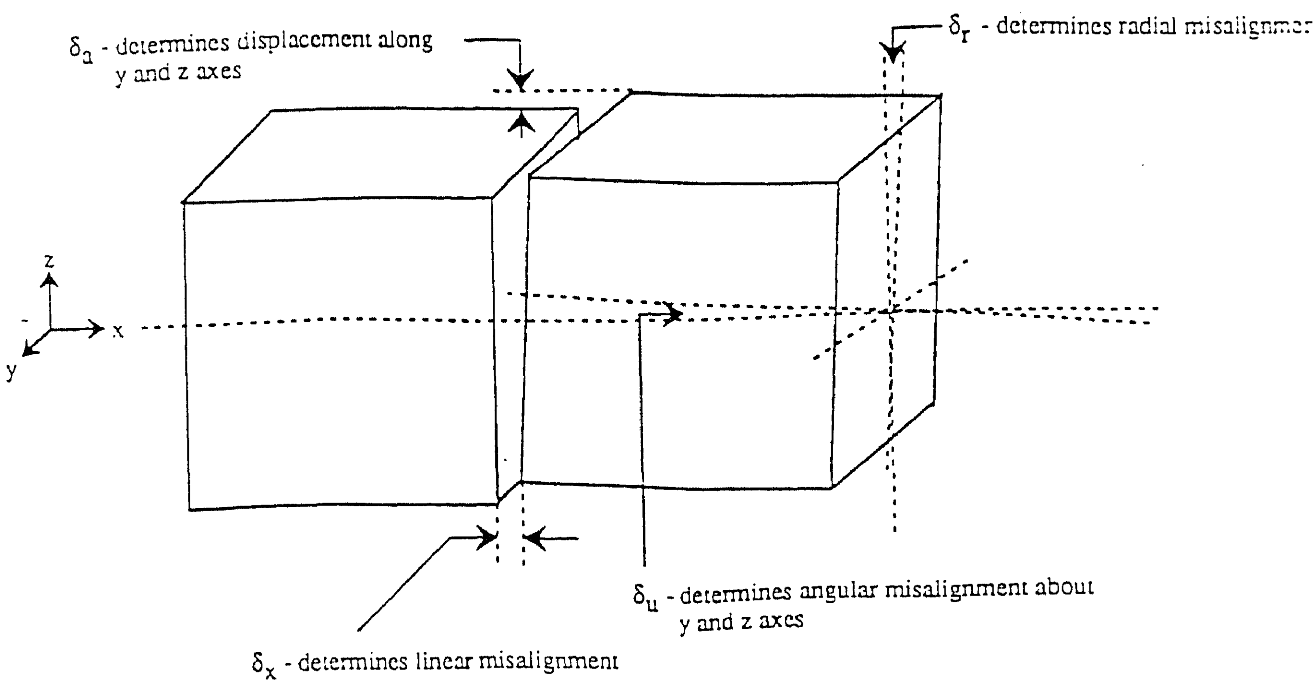


Figure 3.6 Part Misalignments

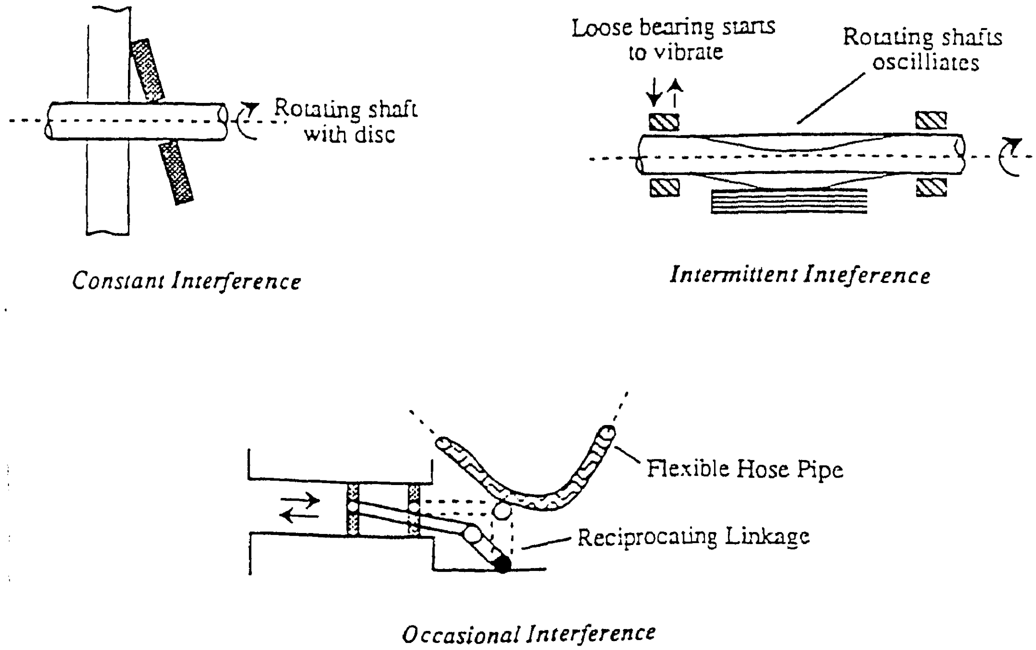


Figure 3.7 Part Interferences

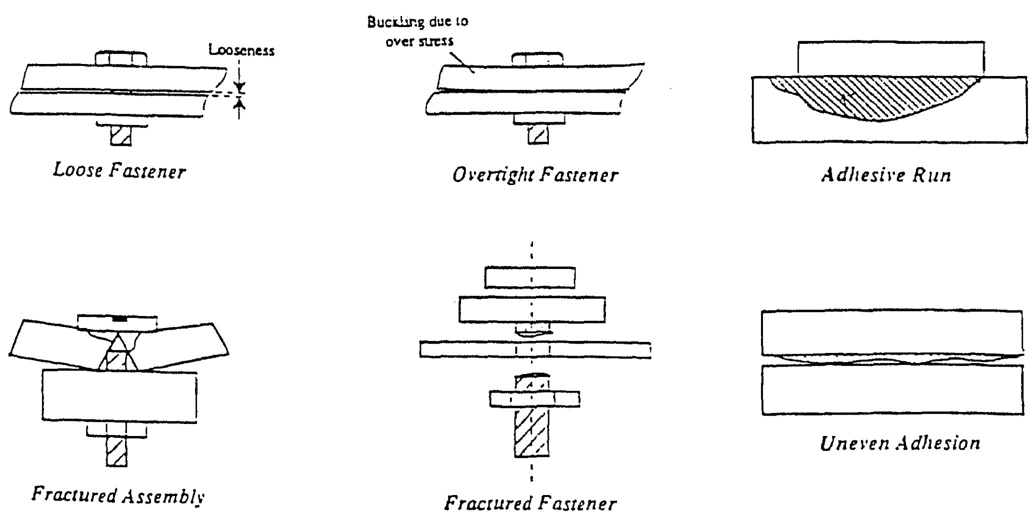


Figure 3.8 Fastener Related Defects

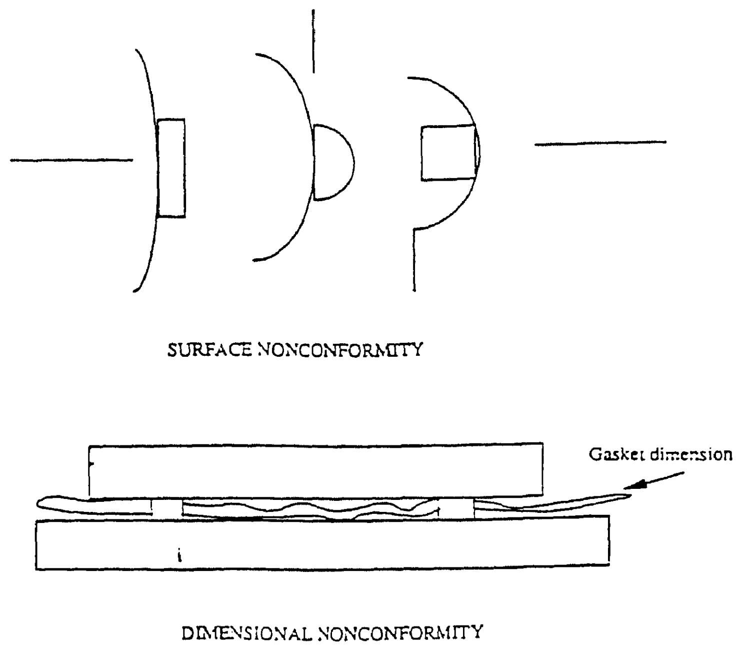


Figure 3.9 Total Nonconformity

CHAPTER 4

CAUSE - EFFECT ANALYSIS OF MANUFACTURING QUALITY DEFECTS IN COMMON ASSEMBLY PROCESSES

4.1 Missing or Misplaced Parts

4.1.1 Missing Part

Missing part is one of the specific defects that is commonly found in mechanical assembly. However under specific circumstances it may also occur in automated assembly. Missing part is mostly associated with the following assembly processes : insertion, fastening, press fit, and snap fit. Activities pertaining to assembly procedure are common to all the four assembly processes having this defect. However there are other factors which are specific to the process that contribute to the occurrence of the defect.

The influencing factors relevant to the insertion process are geometrical features and assembly procedure. If the geometry of parts to be inserted are irregular in shape, the ease to hold the part before inserting in the work is restricted. This will also be a function of precision in positioning/orienting the part before the gripper can hold the part. This accentuates the probability of the part to get released from the gripper hold before being inserted. If the clearance between the mating parts is more to facilitate ease of insertion, then it may result in unrestricted movement of the part along the mating axis. In the absence of sufficient holding mechanism and the orientation of the work the part may have access to come out of the constrained space. Compliance mechanisms are used to check the precision of the insertion process. Failure/absence of compliance mechanism will fail to give feedback if the part has been fully inserted in the work. In such circumstances the chances that the part fall off from the work are increased.

Influencing factors that are relevant to the fastening process are fastening system, material properties and assembly procedure. Fastener strength is often a function of number of fasteners and fastening map. If the magnitude of fastener strength is lesser than the separatory forces, then it is not feasible to hold parts intact. Similarly there is a significant reduction in fastener strength due to the wear in fastener. The fasteners may also be subject to deformation due to their lack of resistance to corrosion and abrasion. The lack of adequate monitoring efforts to assess the fastening efficiency will result in rendering a loosely fastened part go undetected. These are crucial factors for evaluating the assembly efficiency.

Material properties, geometrical features and assembly procedures mostly influence the occurrence of missing part in press fit. The most prevalent problem in press fits is stress relaxation. Stress relaxation occurs due to incongruity of structural properties between the part and the work and results in loss of holding force. Lack of holding mechanism to restrict part displacement along the mating axis, failure/absence of compliance mechanism to assess the press-in efficiency and higher clearance value between the part and the work are other factors that accentuates the occurrence of the defect.

The influencing factors that are relevant to snap fit are material properties and fastening system. Lack of adequate elasticity will result in the part not clearing the interference fully. Then the probability that the part snaps out by itself is very high. Furthermore if the parts are not resistant to abrasion, solvent, and creep the snap area undergoes deformation resulting in snap-out over a period of time. Inadequate friction force between the snapping parts or inappropriate snapping method will result in reduction in snapping strength.

Figure 4.1 illustrates the Cause - Effect analysis for the missing part.

4.1.2 Part Inter Change

Part inter change occurs in most assembly process as a result of inconsistency of the executing organ or as a result of lack of assembly instructions. This defect primarily occurs in mechanical assembly processes. Part inter change is identified with the following processes : insertion, riveting, welding, fastening, press-fit, and snap-fit. The influencing factors that effect the occurrence of the specific defect are geometrical features and assembly procedure.

When all the features in the parts to be assembled are beta symmetric, there is a high possibility for the parts to get swapped. Parts with a combination of features that are beta symmetric and asymmetric can be misoriented by 180 degrees to the assembly axes. In such cases, lack of evident distinguishing features to facilitate easier identification and human inconsistency are the primary reasons for the occurrence of this defect.

If the assembly instructions/procedure is not strictly enforced, the assembly has a high probability to have this defect. In the case of assembly with multiple components, the sequence of arrangement of parts prior to assembly is crucial. Periodical monitoring may be required to assess the sequential integrity of the assembly. The Cause - Effect analysis for part inter change is not process specific. It can be inferred that the defect exists in all mechanical assembly operations with varying probability as a consequence of factors that were earlier identified. For the purpose of avoiding redundancy in the material, Cause - Effect diagram with the process names is illustrated in figure 4.2

4.1.3 Mispositioning

Mispositioning is associated with the riveting, fastening, and welding processes. In all these above mentioned processes the assembly site is not explicitly defined and there exists a possibility to perform the assembly operations even if positioned otherwise. In the riveting process the influencing factors that cause mispositioning are geometrical features,

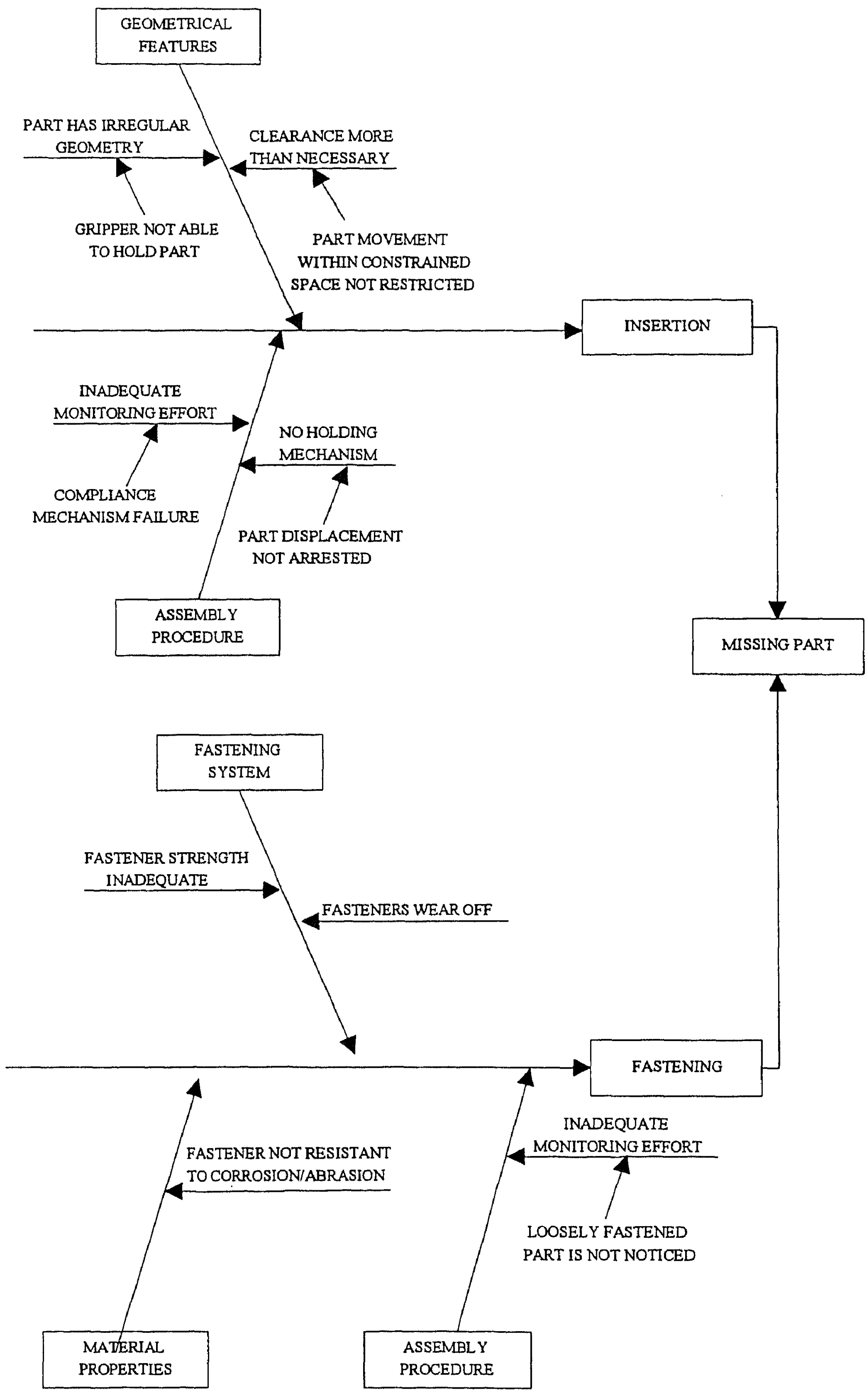


Figure 4.1 Cause - Effect Diagram : Missing Part

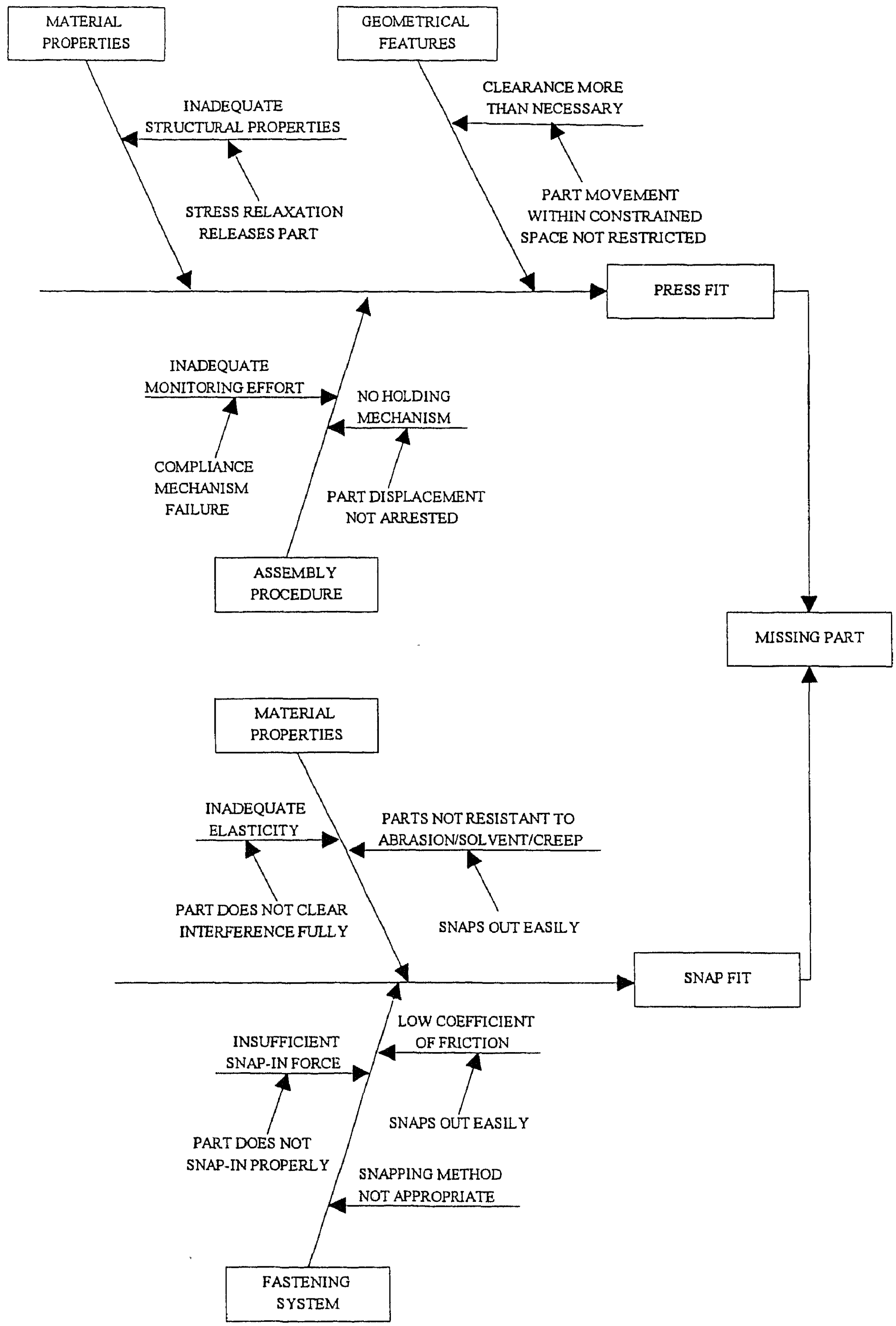


Figure 4.1(continued) Cause - Effect Diagram : Missing Part

fastening system, assembly procedure, and part inter relationships. When the parts to be riveted belong to different geometrical classifications (see Appendix C), the number of contact points between mating parts are less. The difference in geometries between parts leads to difficulty in resting the parts in the desired orientation with respect to each other. This restricts the feasibility to effectively arrest part displacement. The sequence of riveting also has a stipulated influence in restricting part positioning. It may be required to follow a predefined sequence of riveting to preserve positional features and dimensional relationships between parts. Mispositioning can also occur due to lack of fixturing effort. Parts not held rigidly may get mispositioned due to rivet impact.

In the fastening and welding processes, the fastening site should have adequate assess and visual envelope to verify the propriety of positioning. In the absence of which there is a distinct possibility for the parts to be mispositioned. Also in such cases it is difficult to maintain dimensional interrelationships between part. The significance of geometrical classifications to facilitate strong binding between parts and the importance of sequential integrity are similar to the riveting process discussed earlier in this section. Figure 4.3 illustrates the Cause - Effect analysis for mispositioning.

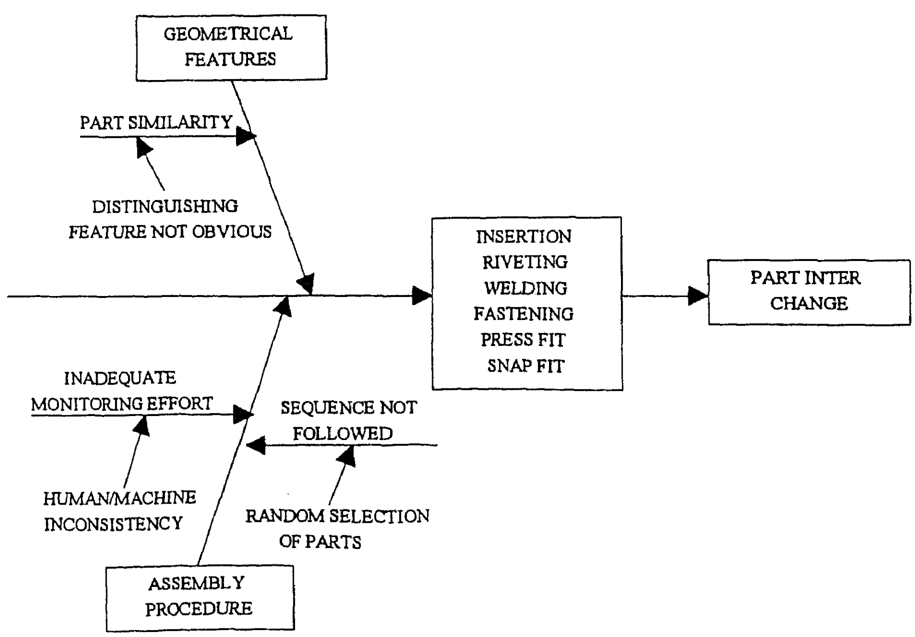


Figure 4.2 Cause - Effect Diagram : Part Inter Change

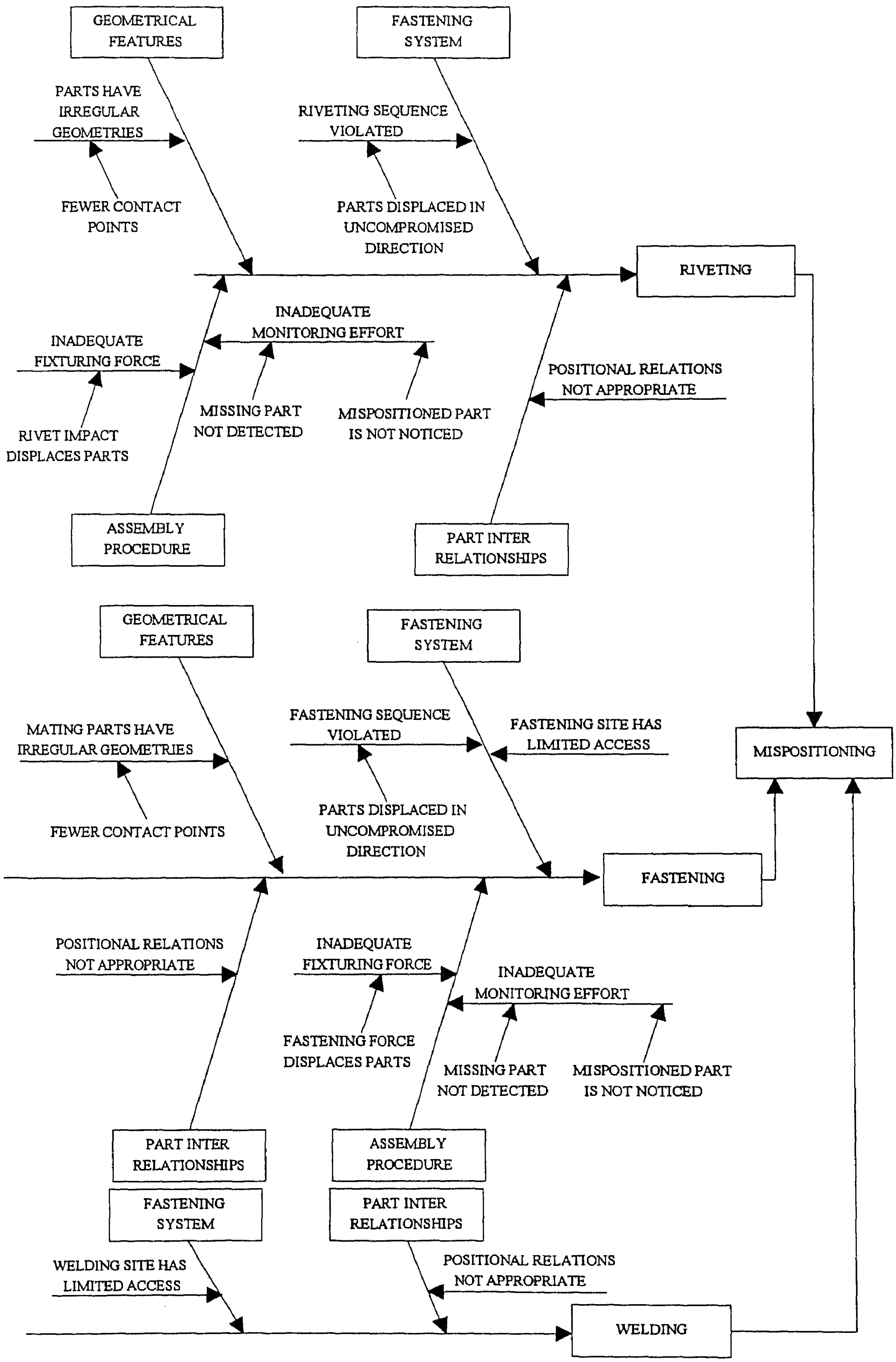


Figure 4.3 Cause - Effect Diagram : Mispositioning

4.2 Part Misalignments

4.2.1 Axial Misalignment

Axial misalignment is one of the widely found quality defects in assembly. The occurrence of this defect in most occasions is due to lack of alignment measures and positioning elements/locators. However in majority of the cases the Cause - Effect analysis for this defect is process specific. Axial misalignment is found to occur in the following processes : insertion, riveting, welding, fastening, press-fit, and snap-fit. Geometrical features and the process by which the part is manufactured are the influencing factors in insertion which effect axial misalignment. The amount of clearance between the part and the work is a crucial factor in insertion. Higher clearance value facilitates ease of inserting the part, while inadequate clearance requires additional force besides having other undesirable consequences. Finding an optimum clearance is imperative to ensure proper alignment between the part and the work. When the part is inserted into a not completely constrained envelope, there is a need for positioning features or locators. These features serve as references to facilitate proper alignment while performing the assembly task. The locators help to preserve the orientation of the part with respect to the unmating space. Furthermore the parts have to be machined with the required dimensional and geometric specifications. For this the tolerance limits of the process and machine in which the parts are manufactured should be greater than the tolerance range of the specifications.

In the riveting process geometrical features, assembly procedure and part inter relationships are the influencing factors that cause axial misalignment. The number of contact points or the type of contact between mating surfaces are crucial to ensure proper alignment. In such cases it is desirable to have parts belonging to the same family of geometrical classification (see chart in Appendix C). The difference in geometries between parts, causes difficulty in resting the parts in the desired orientation with respect to each other and results in an axially misaligned assembly. Commensurate importance should be given to the fixturing procedure. The fixture should be capable of restricting part displacement in uncompromised directions due to rivet impact. The propriety of inter-component dimensional conditions and positional relations are of significant importance when preventing axial misalignments in riveted joints.

Axial misalignments in welded assemblies are influenced by fastening system and part inter relationships. Welded assemblies mostly have axial misalignments due to poor sealing properties as a consequence of inadequate weld strength. The sealing rigidity is proportional to the number of weld sites, surface area of contact per weld site, uniformity of weld surface area, and the welding map. The number of weld sites and the weld surface area per site is determined by evaluating the required sealing force. The weld area uniformity is dependent upon the welding method accuracy. Welding map determines the structural balance of the assembly. Misalignments also occur as a result of mispositioning or as a result of inappropriate inter part positional/dimensional relationships.

Material properties, fastening system, assembly procedure and part inter relationships are the influencing factors that causes a fastened part to be axially misaligned. The compatibility of physical properties between parts in the assembly have a determinatory influence on the axial misalignment. Large differences in coefficient of thermal expansions, corrosive resistance etc. are instances when changes in the functional environment of the part will render the assembly axially misaligned. Inadequate fastener strength can jeopardize the alignment integrity of the assembly. Fastener strength is a function of the number of fasteners participating in the mating and the fastening map used in the assembly. The number of fasteners required are determined by evaluating the force required to bind the parts together. The fastening map determines that the required force is provided without infringing the structural integrity of the assembly. Adequate fasteners in conjunction with an appropriate fastening map will provide an axially aligned assembly. Axial misalignment during the fastening process happens due to inadequate fixturing effort. The fixturing map should be capable to prevent translation of the torque associated with fastening into linear components. The set-up of parts prior to fastening is of paramount importance to the assembly. The propriety of inter-component dimensional conditions and positional relations determines the set-up accuracy which in turn will avoid axial misalignment.

The influencing factors that cause axial misalignment in press-fits are geometrical features, fastening system, assembly procedure, process by which the parts are manufactured, and tolerance inter relationships. When parts belonging to different family of geometric classifications are involved in a press-fit, the work envelope will not be fully constraining. Consummately unconstrained work envelopes have fewer number of mating surfaces and contact points. This results in weak bonding between the work and the part. Furthermore there is a need for positioning elements to orient the unmating features with respect to the assembly axes. These geometric factors have to be evaluated in order to avoid axial misalignment. As discussed in Chapter 3, press-fits involve a press-in force to insert the part into the work. It is imperative that the press-in force should be coaxial to the assembly axis. Any incongruity of the press-in force from the assembly axis will certainly cause axial misalignment. Similarly the magnitude of the fixturing force should be greater than or equal to the press-in force. This will counter possible part/work displacement due to press-in. One of the most vital factors that determine the accuracy of the press-fit is the tolerance inter relationships. Press-fits require strict adherence of tolerance specifications. The process and the machine capabilities determine the tolerance adherence. The tolerance limits of the process and the machine should be wider than the tolerance range of the design specifications. Furthermore the homogeneity of tolerance distribution is also a determining factor. Tolerance distribution is considered to be homogenous when the difference between the upper tolerance limit of the work and the lower tolerance limit of the part is lesser than the maximum permissible clearance between the work and the part.

Axial misalignments in snap-fits are associated with the following influencing factors: material properties, fastening system, process by which the parts are manufactured, and tolerance inter relationships. All snap-fits are designed with interferences which the parts clear to be in a firmly secured position. Parts are subject to tensile stress when clearing the interference. When parts with high elastic moduli are subject to tensile stress, they fail to restore themselves to the original geometry. This causes low locking rigidity and leads to poor sealing properties. The locking rigidity is also a function of the coefficient of friction of the mating surfaces. Surfaces with low coefficients of friction are less grainy and permits dislocation of parts with respect to the mating axis. The resistance of parts to corrosion, solvent, abrasion, and creep are other material properties prevent any deformation/damage at the snapping site thereby prmoting axial alignment. The choice of appropriate snapping method is dependent on the material properties and the type of contact between the mating surfaces. The rigidity of the mechanical interlocking is dependent on the compatibility of material properties and the snapping method. The process by which the parts are manufactured play a crucial role in snap fits. Snap fits as discussed earlier in Chapter 3 are mostly applicable with assembly parts involving plastic and synthetic parts. Most plastic and synthetic parts are molded to required shapes and dimensions. Low molding tolerance or improper tolerance distribution between snapping parts will produce parts which do not meet the design specifications. This results in poor sealing and a weak snap. Figure 4.4 illustrates the Cause - Effect analysis for axial misalignment.

4.2.2 Angular Misalignment

Angualr misalignment is found to occur in processes where the fasteners/links between the parts or the orientation of the parts can be at an angle to the assembly axis. This specific defect is existent in insertion, welding, fastening, press-fit, and snap-fit. The prominent reason for the occurance of this defect is the orientation of the assembly plane

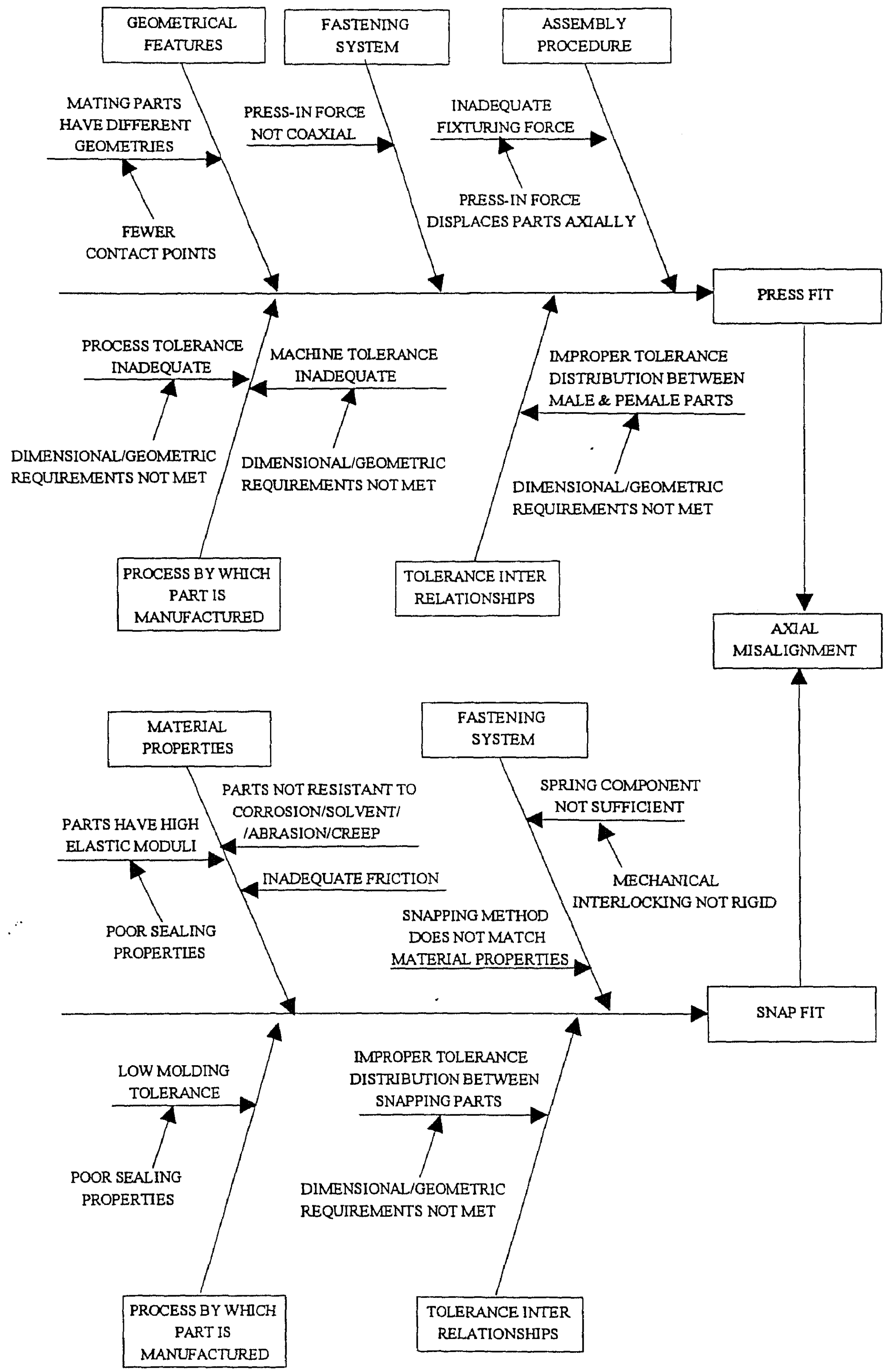


Figure 4.4(continued) Cause - Effect Diagram Axial Misalignment

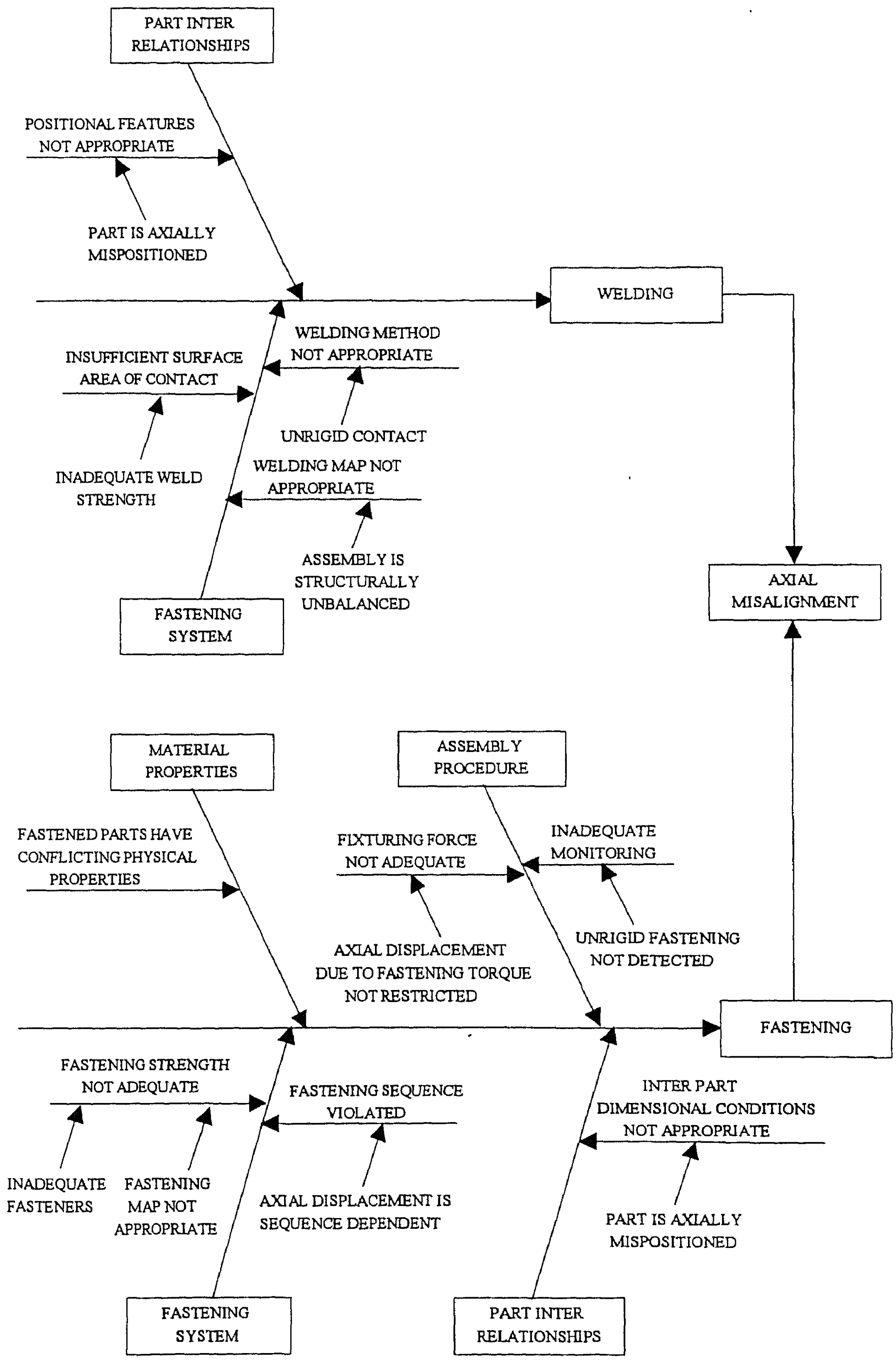


Figure 4.4(continued) Cause - Effect Diagram Axial Misalignment

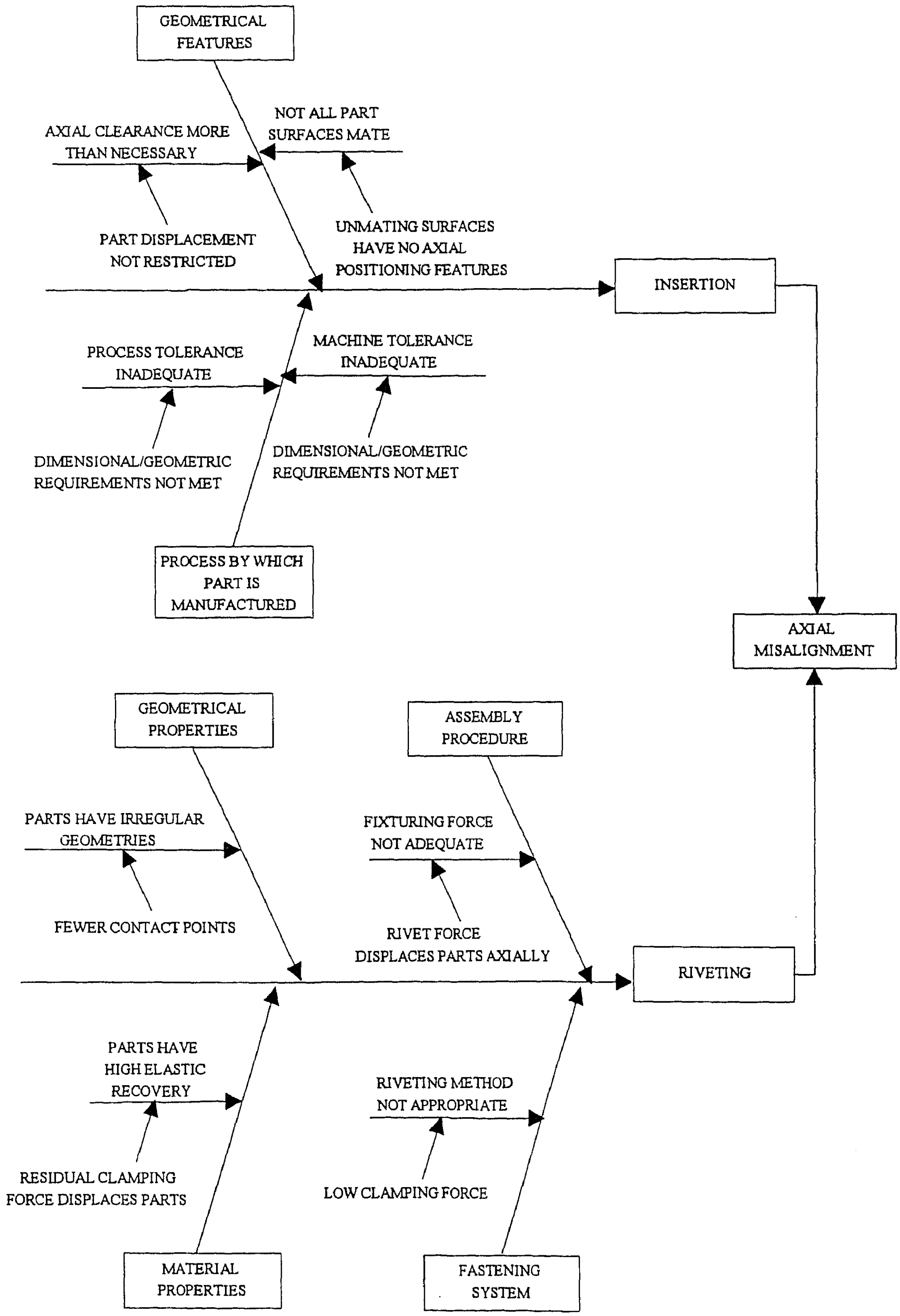


Figure 4.4 Cause - Effect Diagram Axial Misalignment

and inadequate fastener strength. However there are several other factors specific to the concerned process that leads to this type of misalignment.

Geometrical features and the process by which the part is manufactured are the influencing factors causing this specific defect in the insertion process. When alpha symmetric or assymetric parts are involved in the insertion process, the dimension of parts are crucial in determining the correlation between the center of gravity and their geometric center. The farther the center of gravity is from their the geometric center, the more the moment acting on the part tending to topple the part. Let us for example consider the case of cover-and-a-box assembly (Abdel-Malek 1989) where the assembly involving complex geometries are analyzed in detail (see figure 4.5) It can be inferred

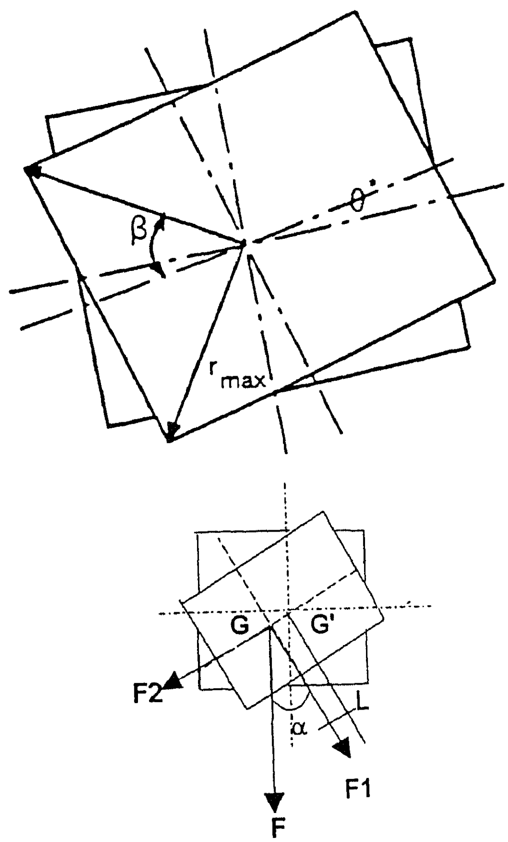


Figure 4.5 Cover-and-a-box assembly

from the diagram that the magnitude of displacement is a funtion of r_{max} and the repeatability of the executing organ. This means that for the same value of deflection angle, the extent of displacement will become more pronounced with increase in thedimensions of parts. Let us assume that G and G' represent the center of gravity and the geometric center of parts respectively and let L be the distance between them. Let F be the force exerted by the natural action of gravity. It can be seen that the moment F1*L tends to topple the cover, where $F1 = F * \sin(\alpha)$. The magnitude of deflection is proportional to the distance L, which in turn is proportional to the dimension of the parts. These assembly considerations however are more accentuated in manual assembly as opposed to automatic assembly due to fixturing constraints. Part inclination can also occur if the insertion envelope is located at an angle to the horizontal or if there is excessive clearance between the part and the work. In such cases angular constraining elements are very important. Similarly if the part is not inserted into a fully constrained envelope, positioning elements in the unconstrained area are required. These elements facilitate orientation of parts in free space and avoid mispositioning. Furthermore the process and the machine used to fabricate the parts should be capable to provide the required dimensional and geometric specifications of the design. In such cases usage of a reliable process is of paramount importance. The process by which the part is manufactured is considered to be reliable when the specified tolerance is within the tolerance limits of the process and the machine.

The influencing factors associated with angular misalignment in welding are assembly procedure and fastening system. The incapability to hold the parts rigidly is the overriding reason for a welded assembly to have this defect. Weld strength is a function of number of welds in the mating area and the welding map. The surface area of binders between the mating surfaces is proportional to the number of welds. Larger the surface area, more the weld strength. The welding map determines the pattern in which the binders are arranged in the assembly plane. Appropraite combination of the welding map and the optimum number of weld structurally balances the assembly. The assembly procedure should include efforts to ensure accurate positioning of the part prior to assembly and maintaining it until the completion of the assembly task.

Angular misalignment in fastened assemblies is influenced by the following factors: fastening system, part inter relationships and assembly procedure. The fastener strength required to hold parts rigidly is determined by the number of fasteners in the mating plane and the fastening map. Inadequate number of fastners will permit unrestricted degree of freedom of parts along one or more axis. Structural equilibrium of the assembly is provided by the fastening map. The fastening map determines the position of the fasteners in the assembly plane such that sum of the forces and moments with respect to any point in the assembly plane is equal to zero. It is important that the direction of the fastening force be orthogonal to the mating plane to preserve the alignment integrity of the assembly. When there are multiple fastners in the assembly, it is imperative to identify and follow the appropriate sequence of fastening in accordance with the fastening map. The assembly procedure should include efforts to ensure accurate positioning of the part prior to assembly and adequate fixturing force to maintain it until the completion of the assembly task . The propriety of inter-component dimensional conditions and positional relations are of significant importance when preventing angular misalignment in fastened joints.

In Press fits the geometry of the press-in site and the parts are crucial factors. When the press-in envelope is not parallel/coaxial to the assembly axis, the forces acting on the inclined plane tend to angularly dislocate the part. Similarly the center of mass tends to angularly dislocte the part when the part has asymmetrical inclined features. When the press-in force is not parallel to the assembly axis the assembly is likely to have this defect. Furthermore the process and the machine used to manufacture the part should be capable to provide the required dimensional and geometric specifications. Figure 4.5 illustrates the Cause - Diagram for angular misalignment.

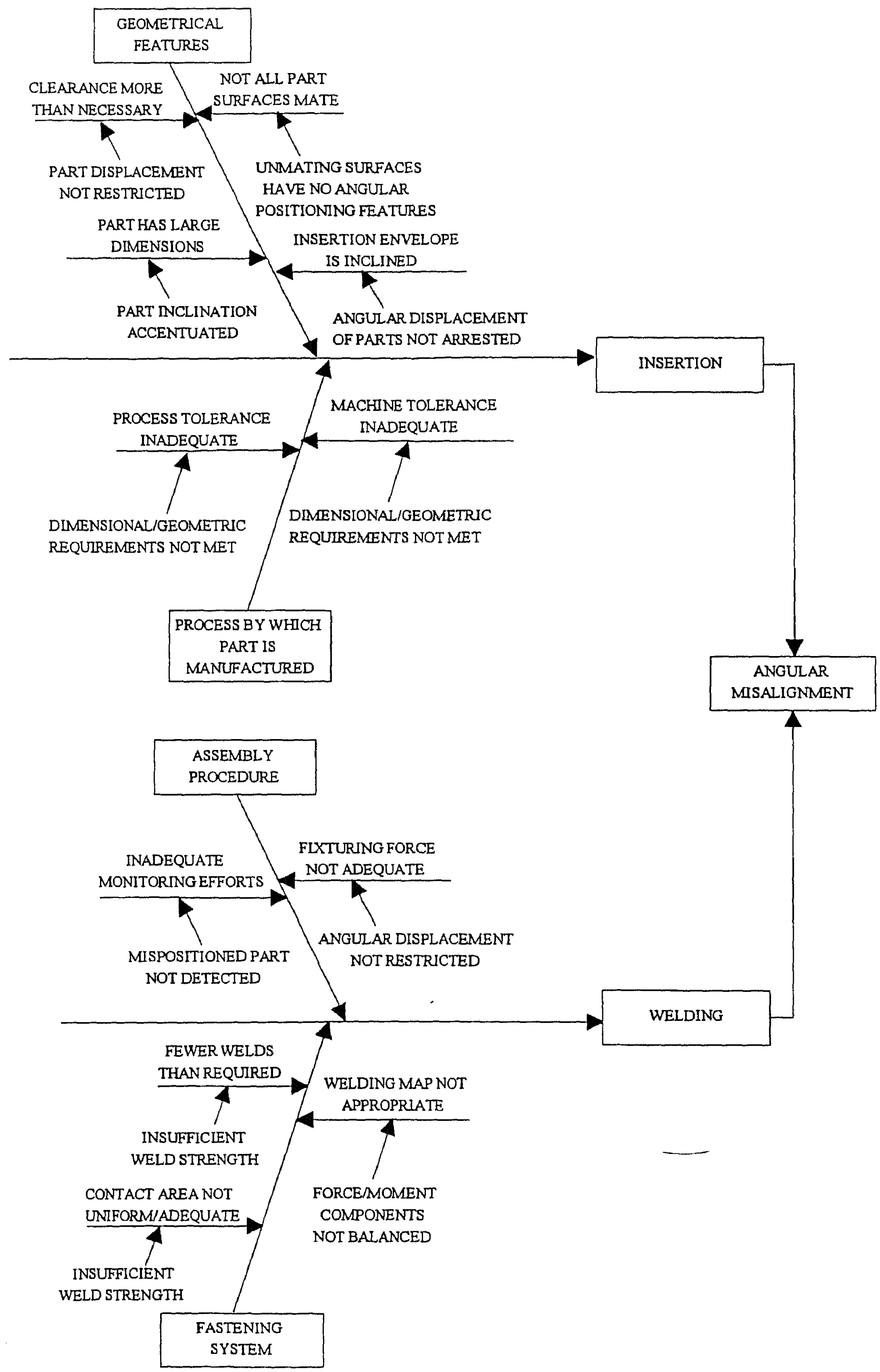


Figure 4.6 Cause - Effect Diagram Angular Misalignment

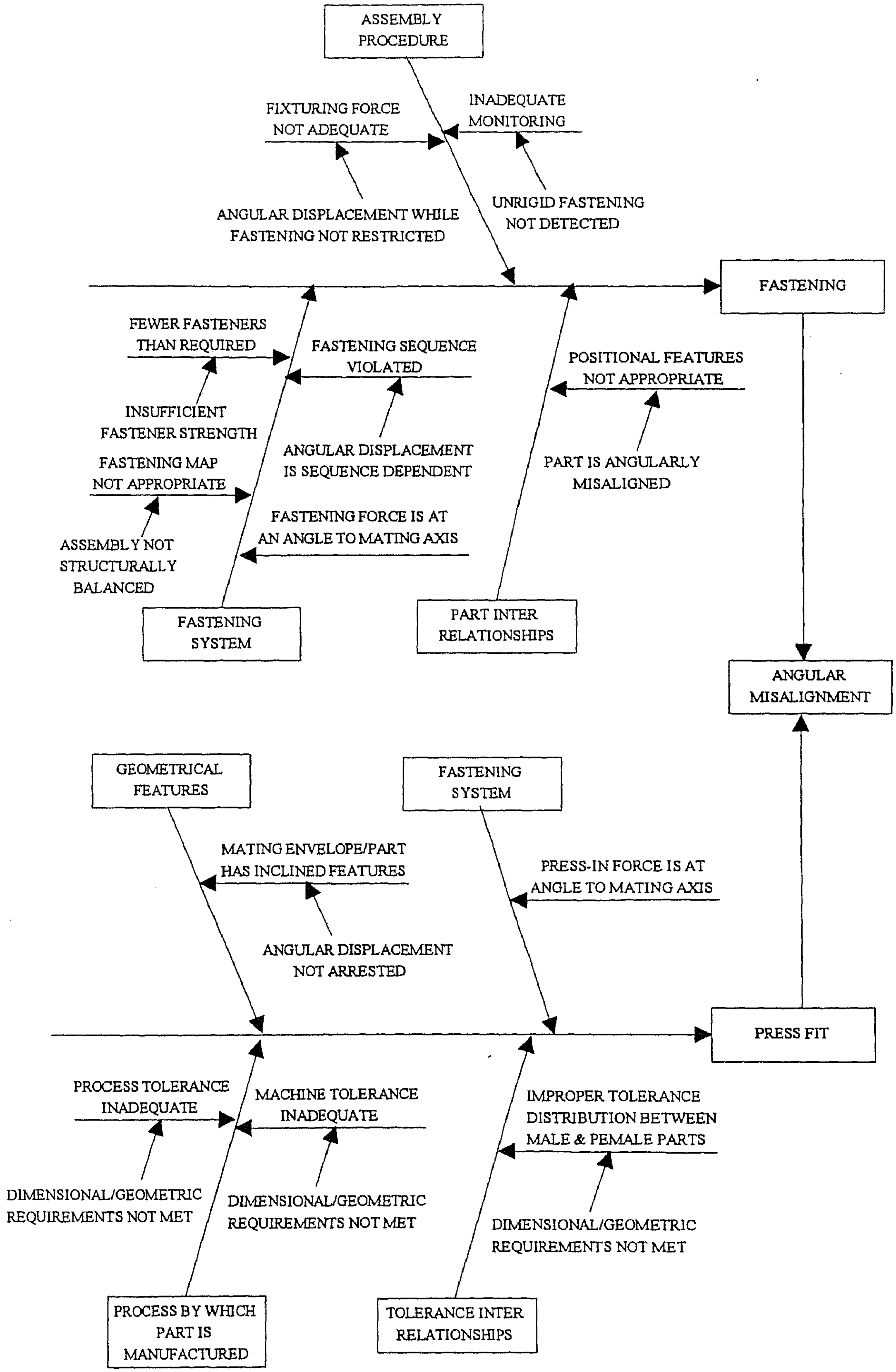


Figure 4.6(continued) Cause - Effect Diagram Angular Misalignment

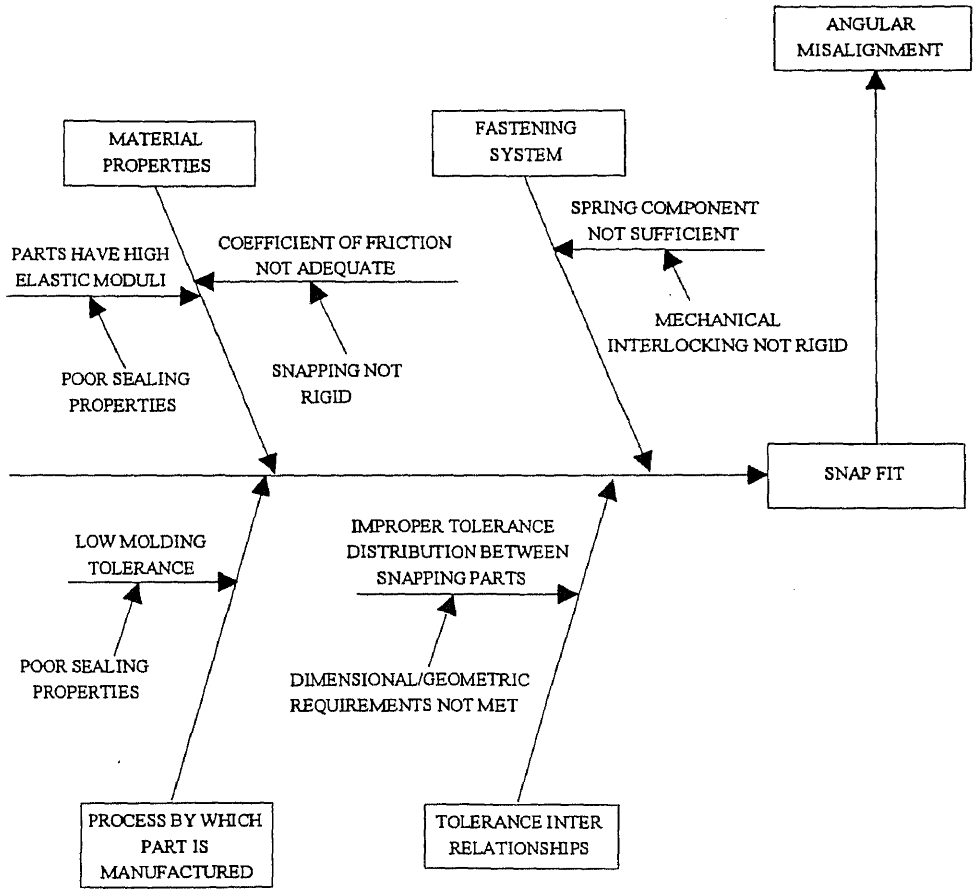


Figure 4.6(continued) Cause - Effect Diagram Angular Misalignment

4.2.3 Linear Misalignment

Linear misalignment in most assembly occurs due to the lack of alignment measures and positioning elements/locators. However in majority of the cases the Cause - Effect analysis for this defect is process specific. Linear Misalignment is found to occur in the following processes : insertion, riveting, welding, fastening, press-fit, and snap-fit. Geometrical features and the process by which the part is manufactured are the influencing factors in insertion which effect linear misalignment. The amount of clearance between the part and the work is a crucial factor in insertion. Higher clearance value facilitates ease of inserting the part, while inadequate clearance requires additional force besides having other undesirable consequences. Finding an optimum clearance is imperative to ensure proper alignment between the part and the work. When the part is inserted into a not completely constrained envelope, there is a need for positioning features or locators. These features serve as references to facilitate proper alignment while performing the assembly task. The locators help to preserve the orientation of the part with respect to the unmating space. Furthermore the parts have to be machined with the required dimensional and geometric specifications. For this the tolerance limits of the process and machine in which the parts are manufactured should be greater than the tolerance range of the specifications.

In the riveting process geometrical features, assembly procedure and part inter relationships are the influencing factors that cause linear misalignment. The number of contact points or the type of contact between mating surfaces are crucial to ensure proper alignment. In such cases it is desirable to have parts belonging to the same family of geometrical classification (see Chart 1 in appendices). The difference in geometries between parts, causes difficulty in resting the parts in the desired orientation with respect to each other and results in a linearly misaligned assembly. Commensurate importance should be given to the fixturing procedure. The fixture should be capable of restricting part displacement in uncompromised directions due to rivet impact. The propriety of inter-component dimensional conditions and positional relations are of significant importance when preventing linear misalignments in riveted joints.

Linear misalignments in welded assemblies are influenced by fastening system and part inter relationships. Welded assemblies mostly have linear misalignments due to poor sealing properties as a consequence of inadequate weld strength. The sealing rigidity is proportional to the number of weld sites, surface area of contact per weld site, uniformity of weld surface area, and the welding map. The number of weld sites and the weld surface area per site is determined by evaluating the required sealing force. The weld area uniformity is dependent upon the welding method accuracy. Welding map determines the structural balance of the assembly. Misalignments also occur as a result of mispositioning or as a result of inappropriate inter part positional/dimensional relationships.

Material properties, fastening system, assembly procedure and part inter relationships are the influencing factors that causes a fastened part to be linearly misaligned. The compatibility of physical properties between parts in the assembly have a determinatory influence on the linear misalignment. Large differences in coefficient of thermal expansions, corrosive resistance etc. are instances when changes in the functional environment of the part will render the assembly linearly misaligned. Inadequate fastener strength can jeopardize the alignment integrity of the assembly. Fastener strength is a function of the number of fasteners participating in the mating process and the fastening map used in the assembly. The number of fasteners required are determined by evaluating the force required to bind the parts together. The fastening map determines that the required force is provided without infringing the structural integrity of the assembly. Adequate fasteners in conjunction with an appropriate fastening map will provide a linearly aligned assembly. Linear misalignment during the fastening process happens due to inadequate fixturing effort. The fixturing map should be capable to prevent translation of the torque associated with fastening into linear components. The set-up of parts prior to fastening is of paramount importance to the assembly. The propriety of inter-component dimensional conditions and positional relations determines the set-up accuracy which in turn will avoid linear misalignment.

The influencing factors that cause linear misalignment in press-fits are geometrical features, fastening system, assembly procedure, process by which the parts are manufactured, and tolerance inter relationships. When parts belonging to different family of geometric classifications are involved in a press-fit, the work envelope will not be fully constraining. Consummately unconstrained work envelopes have fewer number of mating surfaces and contact points. This results in weak bonding between the work and the part. Furthermore there is a need for positioning elements to orient the unmating features with respect to the assembly axes. These geometric factors have to be evaluated in order to avoid linear misalignment. As discussed in Chapter 3, press-fits involve a press-in force to insert the part into the work. It is imperative that the press-in force should be coaxial to the assembly axis. Any incongruity of the press-in force from the assembly axis will certainly cause linear misalignment. Similarly the magnitude of the fixturing force should be greater than or equal to the press-in force. This will counter possible part/work displacement due to press-in. One of the most vital factors that determine the accuracy of the press-fit is the tolerance inter relationships. Press-fits require strict adherence of tolerance specifications. The process and the machine capabilities determine the tolerance adherence. The tolerance limits of the process and the machine should be wider than the tolerance range of the design specifications. Furthermore the homogeneity of tolerance distribution is also a determining factor. Tolerance distribution is considered to be homogenous when the difference between the upper tolerance limit of the work and the lower tolerance limit of the part is lesser than the maximum permissible clearance between the work and the part.

Linear misalignments in snap-fits are associated with the following influencing factors: material properties, fastening system, process by which the parts are manufactured, and tolerance inter relationships. All snap-fits are designed with interferences which the parts clear to be in a firmly secured position. Parts are subject to tensile stress when clearing the interference. When parts with high elastic moduli are subject to tensile stress, they fail to restore themselves to the original geometry. This causes low locking rigidity and leads to poor sealing properties. The locking rigidity is also a function of the coefficient of friction of the mating surfaces. Surfaces with low coefficients of friction are less grainy and permits dislocation of parts with respect to the mating axis. The resistance of parts to corrosion, solvent, abrasion, and creep are other material properties prevent any deformation/damage at the snapping site thereby promoting linear alignment. The choice of appropriate snapping method is dependent on the material properties and the type of contact between the mating surfaces. The rigidity of the mechanical interlocking is dependent on the compatibility of material properties and the snapping method. The process by which the parts are manufactured play a crucial role in snap fits. snap fits as mentioned earlier in Chapter 3 are mostly applicable with assembly parts involving plastic and synthetic parts. Most plastic and synthetic parts are molded to required shapes and dimensions. Low molding tolerance or improper tolerance distribution between snapping parts will produce parts which do not meet the design specifications. This results in poor sealing and a weak snap. Figure 4.6 illustrates the Cause - Effect analysis for linear misalignment.

4.2.4 Radial Misalignment

Rngualr misalignment is found to occur in processes where the fasteners/links between the parts or the orientation of the parts can be at an angle to the assembly axis. This specific defect is existent in insertion, welding, fastening, press-fit, and snap-fit. The most prominent reason for the occurance of this defect is the orientation of the assembly plane and inadequate fastener strength. However there are several other factors specific to the concerned process that leads to this type of misalignment.

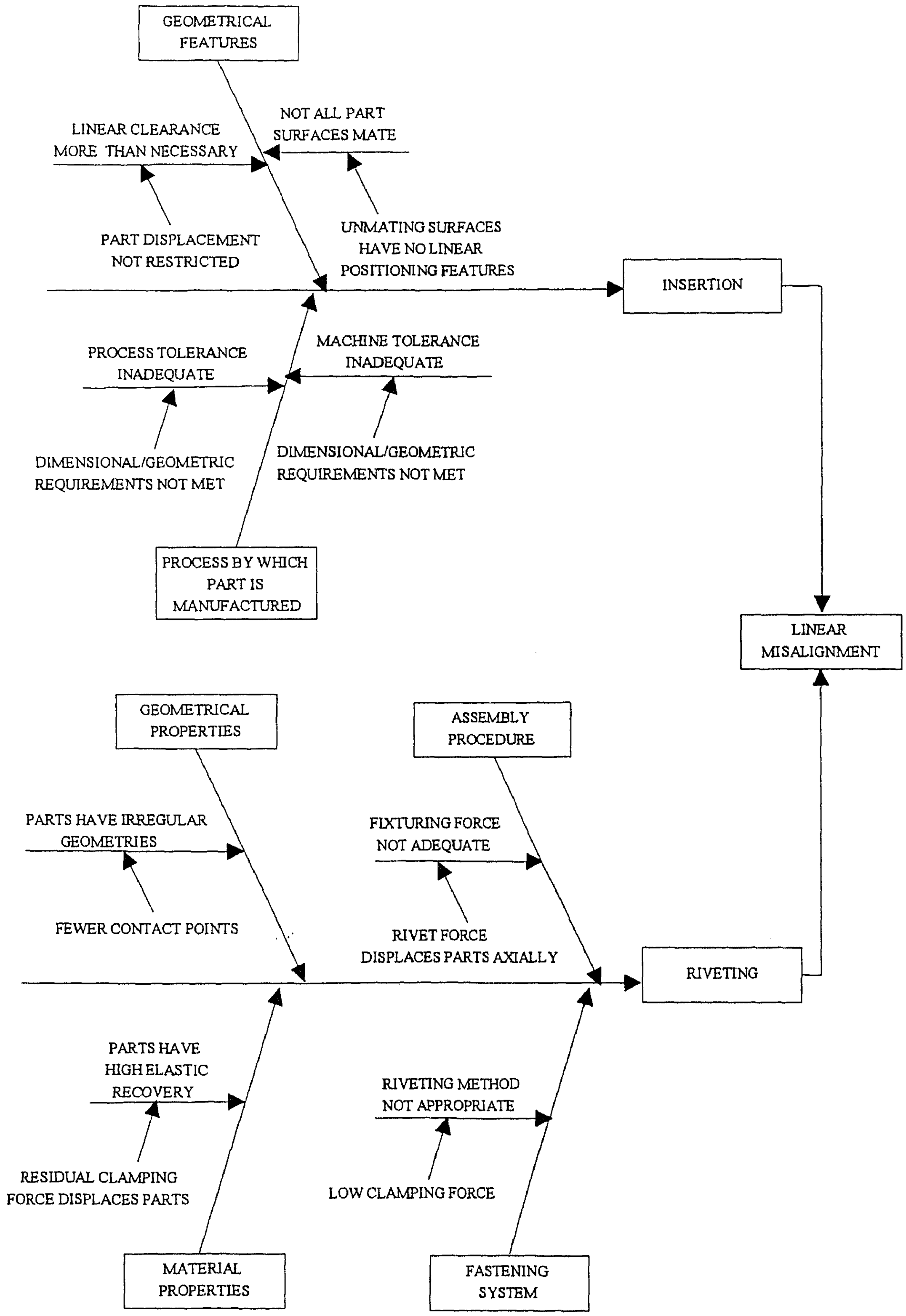


Figure 4.7 Caůse - Effect Diagram Linear Misalignment

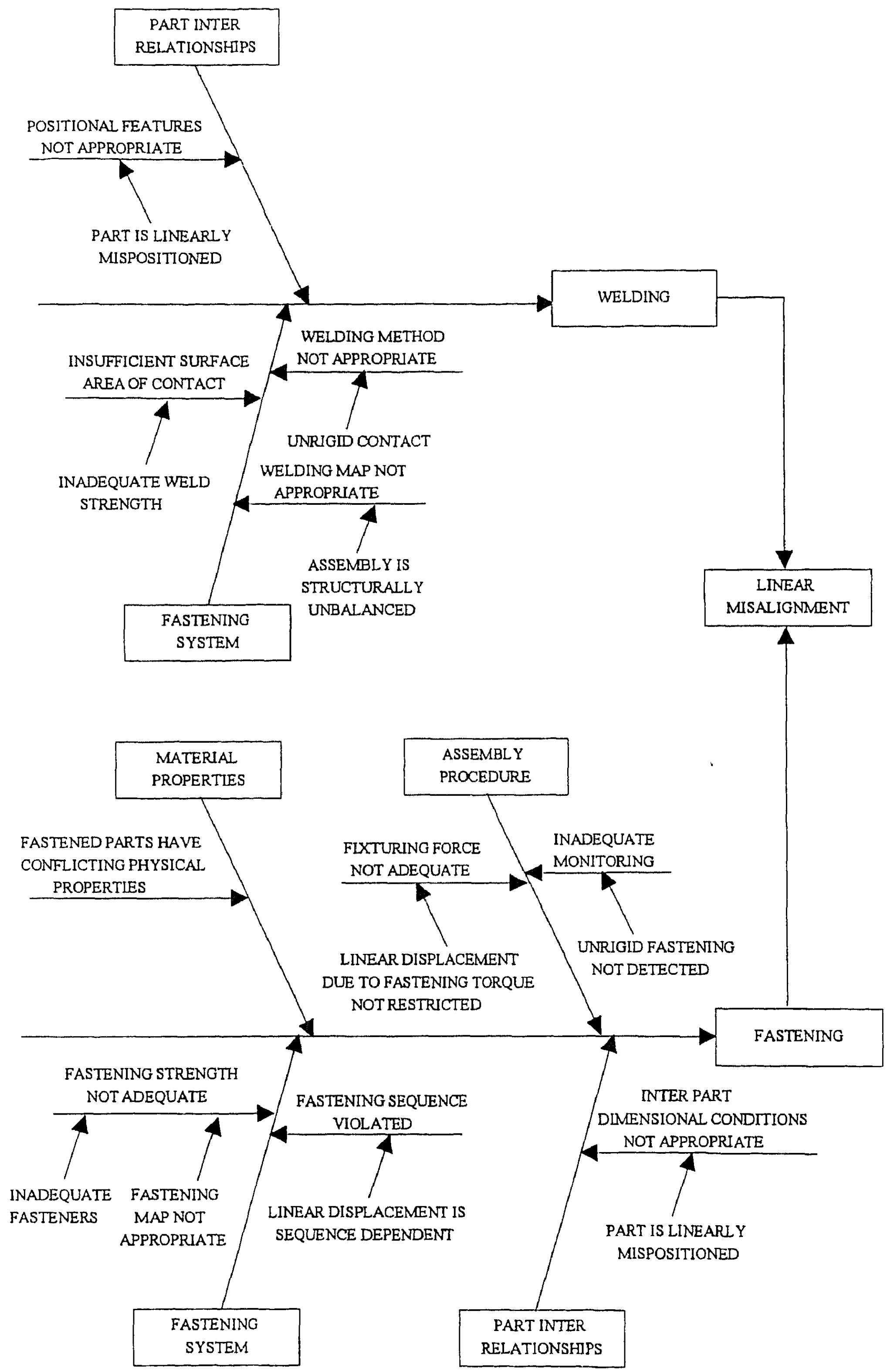


Figure 4.7(continued) Cause - Effect Diagram Linear Misalignment

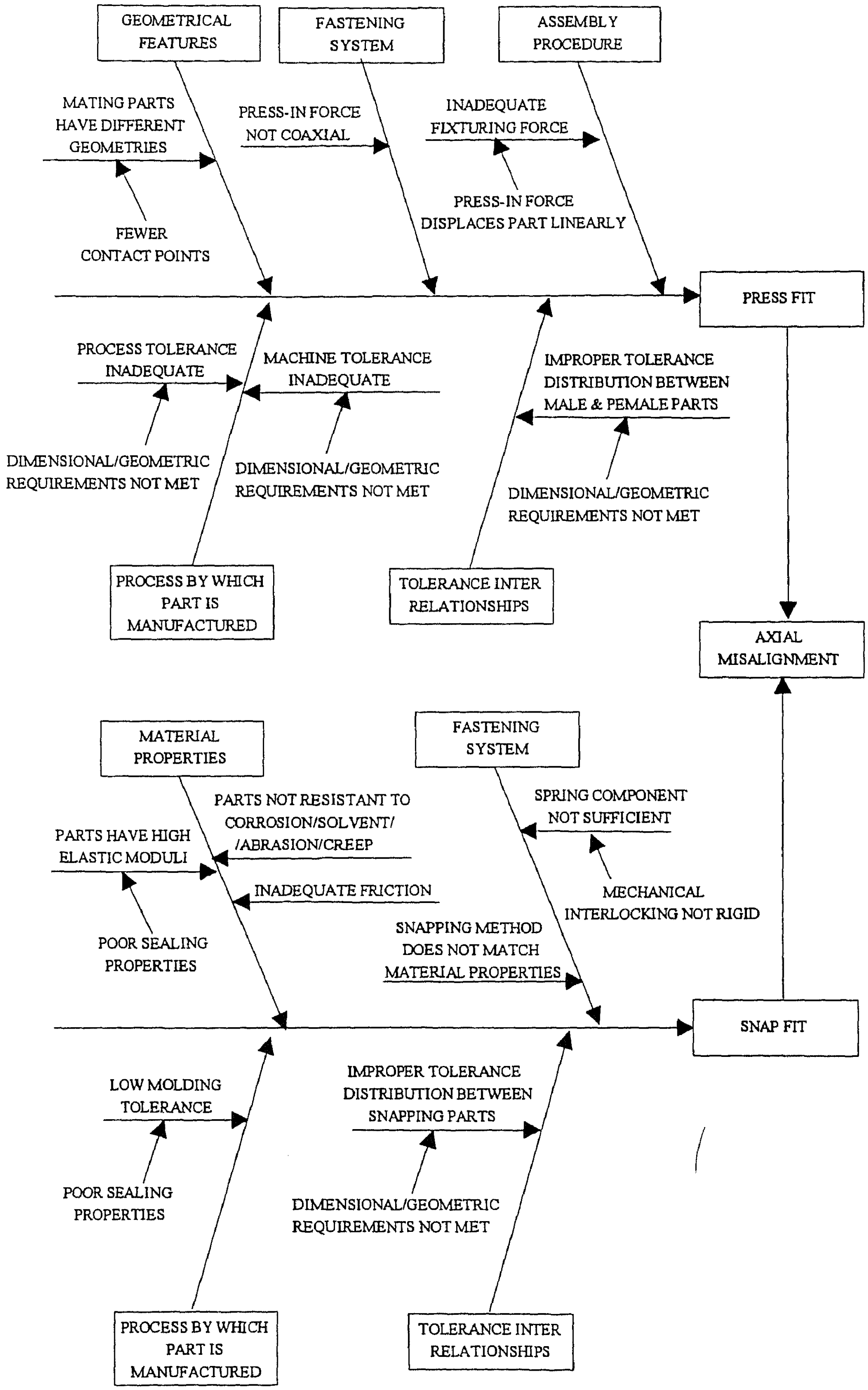


Figure 4.7(continued) Cause - Effect Diagram Linear Misalignme

Geometrical features and the process by which the part is manufactured are the influencing factors causing this specific defect in the insertion process. When alpha symmetric or assymetric parts are involved in the insertion process, the dimension of parts are crucial in determing the correlation between the center of gravity and their geometric center. Farther the center of gravity from their the geometric center, more the moment acting on the part tending to topple the part. In the absence of appropriate constraining elements this will cause part inclination, the magnitude of which is dependent on the dimension of parts. Part inclination can also occur if the insertion envelope is located at an angle to the horizontal or if there is excessive clearance between the part and the work. In such cases angular constraining elements are very important. Similarly if the part is not inserted into a fully constrained envelope, positioning elements in the unconstrained area are required. These elements facilitate orientation of parts in free space and avoid mispositioning. Furthermore the process and the machine used to fabricate the parts should be capable to provide the required dimensional and geometric specifications of the design. In such cases usage of a reliable process is of paramount importance. The process by which the part is manufactured is considered to be reliable when the specified tolerance is within the tolerance limits of the process and the machine.

The influencing factors associated with radial misalignment in welding are assembly procedure and fastening system. The incapability to hold the parts rigidly is the overriding reason for a welded assembly to have this defect. Weld strength is a function of number of welds in the mating area and the welding map. The surface area of binders between the mating surfaces is proportional to the number of welds. Larger the surface area, more the weld strength. The welding map determines the pattern in which the binders are arranged in the assembly plane. Appropraite combination of the welding map and the optimum number of weld structurally balances the assembly. The assembly procedure should include efforts to ensure accurate positioning of the part prior to assembly and maintaining it until the completion of the assembly task.

Radial misalignment in fastened assemblies is influenced by the following factors: fastening system, part inter relationships and assembly procedure. The fastener strength required to hold parts rigidly is determined by the number of fasteners in the mating plane and the fastening map. Inadequate number of fastners will permit unrestricted degree of freedom of parts along one or more axis. Structural equilibrium of the assembly is provided by the fastening map. The fastening map determines the position of the fasteners in the assembly plane such that sum of the forces and moments with respect to any point in the assembly plane is equal to zero. It is important that the direction of the fastening force be orthogonal to the mating plane to preserve the alignment integrity of the assembly. When there are multiple fastners in the assembly, it is imperative to identify and follow the appropriate sequence of fastening in accordance with the fastening map. The assembly procedure should include efforts to ensure accurate positioning of the part prior to assembly and adequate fixturing force to maintain it until the completion of the assembly task . The propriety of inter-component dimensional conditions and positional relations are of significant importance when preventing radial misalignment in fastened joints.

In Press fits the geometry of the press-in site and the parts are crucial factors. When the press-in envelope is not parallel/coaxial to the assembly axis, the forces acting on the inclined plane tend to angularly dislocate the part. Similarly the center of mass tends to angularly dislocte the part when the part has asymmetrical inclined features. When the press-in force is not parallel to the assembly axis the assembly is likely to have this defect. Furthermore the process and the machine used to manufacture the part should be capable to provide the required dimensional and geometric specifications. Figure 4.7 illustrates the Cause - Diagram for radial misalignment.

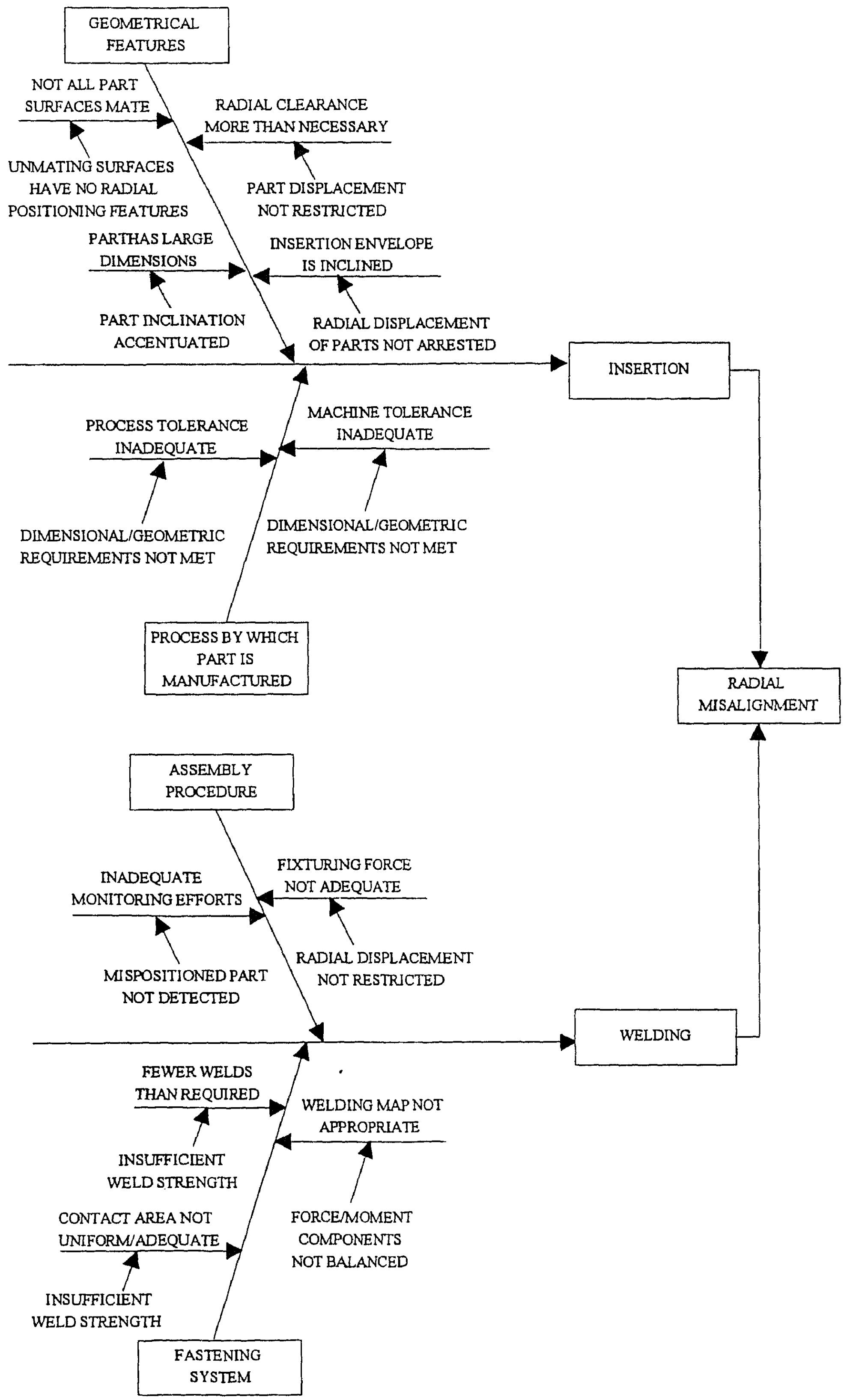


Figure 4.8 Cause - Effect Diagram Radial Misalignment

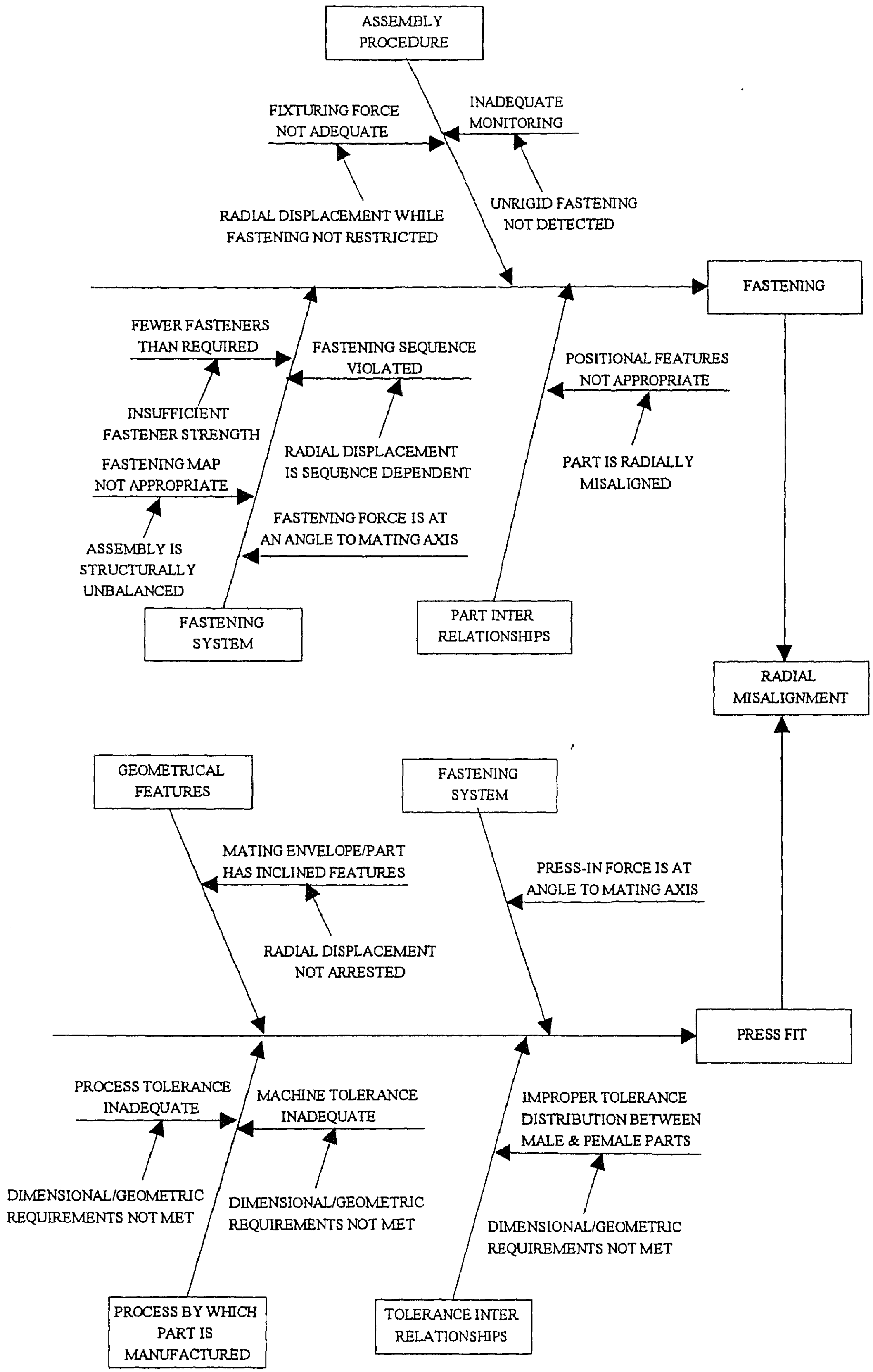


Figure 4.8(continued) Cause - Effect Diagram Radial Misalignment

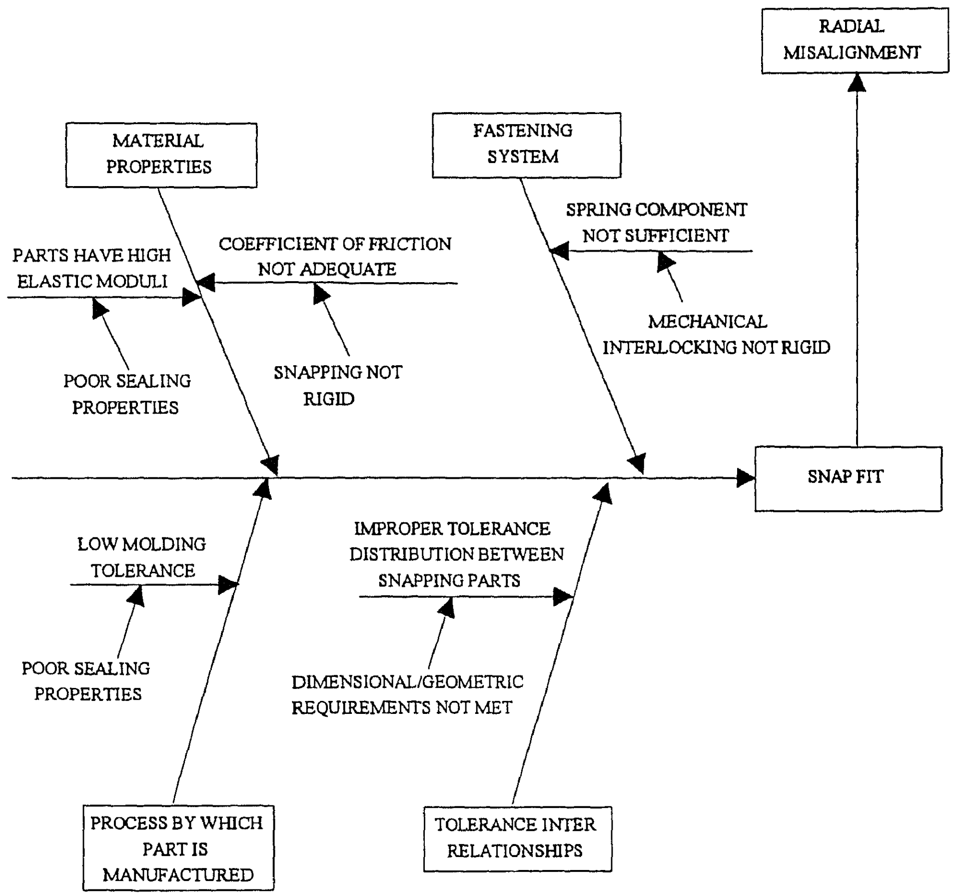


Figure 4.8(continued) Cause - Effect Diagram Radial Misalignment

4.3 Part Interferences

4.3.1 Constant Interference

Part interference is a prominent defect common to assembly processes, where unplanned contact is established between the moving member(s) of the assembly and the static part(s). The occurrence of this defect is mainly attributed to nonadherence of the stipulated assembly procedure. However this defect does occur due to other assembly related reasons also. Constant interference is found to occur in insertion, welding, fastening, press-fit and snap-fit. In the insertion process, geometrical features, assembly procedure, and material properties are the influencing factors related to this defect. Mating features between the part and the work are potential areas of constant interference in insertion. When the work envelope/part is not fabricated in conformance to the specifications, the part moves back and forth within the constrained space depending upon the orientation of the work, causing constant interference. Similar interferences occur due to excessive clearance between the part and the work. When more than one part is inserted into the work, it is imperative that the assembly procedure be strictly adhered. Sequential insertion avoids misplacing/mispositioning of parts. Adequate monitoring effort prevents missing part. Missing or misplaced parts seriously influence constant interference in insertion. Part and work with significantly different material properties can lead to uncongenial circumstances. Large differences in the coefficients of expansion, resilient/malleable parts that are easily deformable, are instances when incompatibility of material properties can cause constant interference.

Fastening system and assembly procedure are the influencing factors pertaining to constant interference in welded assemblies. The most important factor in welding is the capability of the welding method to be able to provide the desired type of contact. The conformance of the process to specifications while establishing the desired type of contact is dependent on the welding location and the welding map. Welding in the boundaries of the parts are considered to be unfavorable sites both from the point of contact rigidity and assembly difficulty. Appropriate welding map structurally balances the assembly. When the assembly consists of several welding sites at discrete intervals, the stipulated sequence of welding should be followed. Violation of sequence may result in unplanned orientation or deposits which will cause constant interference.

Constant interference in fastened assemblies are due to deficiencies in the fastening system and assembly procedure. The method of fastening should be able to provide the required contact rigidity. Interference occurs when the fastening method is not able to provide the necessary torque. When the assembly plane has multiple fasteners, the established sequence should be followed. Misalignments occur when the sequence of assembly is violated. This can cause unplanned contact of the part with the neighboring surfaces and can lead to constant interference.

The influencing factors associated with this specific defect in press-fits are the following: fastening system, assembly procedure and the process by which the parts are manufactured. The thrust mechanism should be able to provide the required press-in force to consummately insert the part inside the work envelope. Inadequate press-in force will leave the part protruding more than the estimated value. This protrusion establishes unplanned contact with the neighboring parts. Compliance mechanisms monitor the propriety of press-in. These mechanisms give feedback about the position and orientation of the part within the constrained space. Failure or absence of compliance mechanism will hamper the assembly evaluation procedure. The process by which the parts are manufactured should be able to meet the required dimensional/geometric requirements. Appropriate evaluation of process and machine capabilities has to be conducted. For this purpose, the tolerance limits of the process and the machine should be greater than the tolerance range of the specifications. Parts with high resiliency or malleability should be avoided in press-fits. Resilient or malleable parts are susceptible to deformation during material handling or assembly process. Deformation of part surfaces will lead to constant interference in press-fits. Figure 4.8 illustrates the Cause - Effect diagram for this defect.

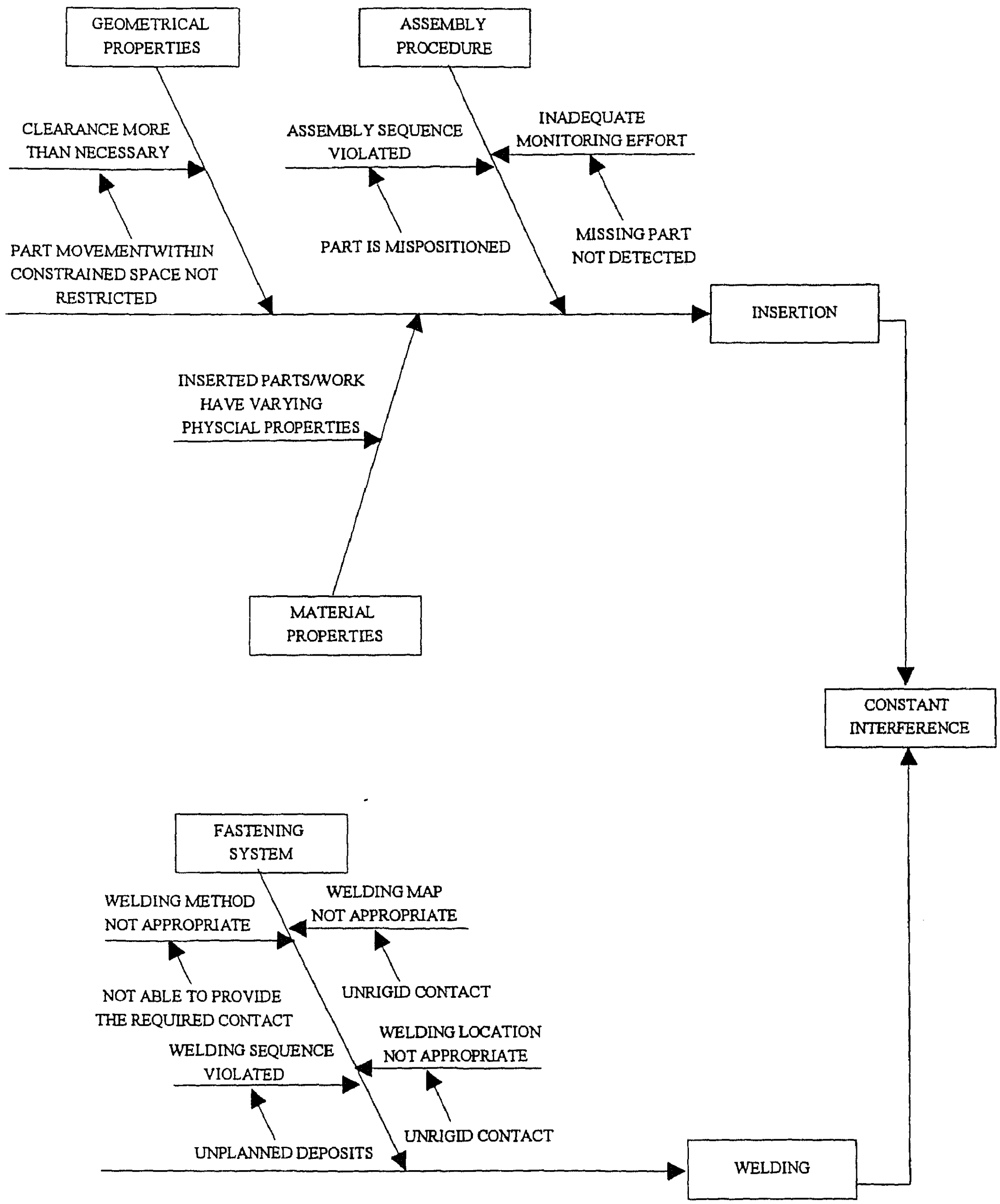


Figure 4.9 Cause - Effeect Diagram Constant Interference

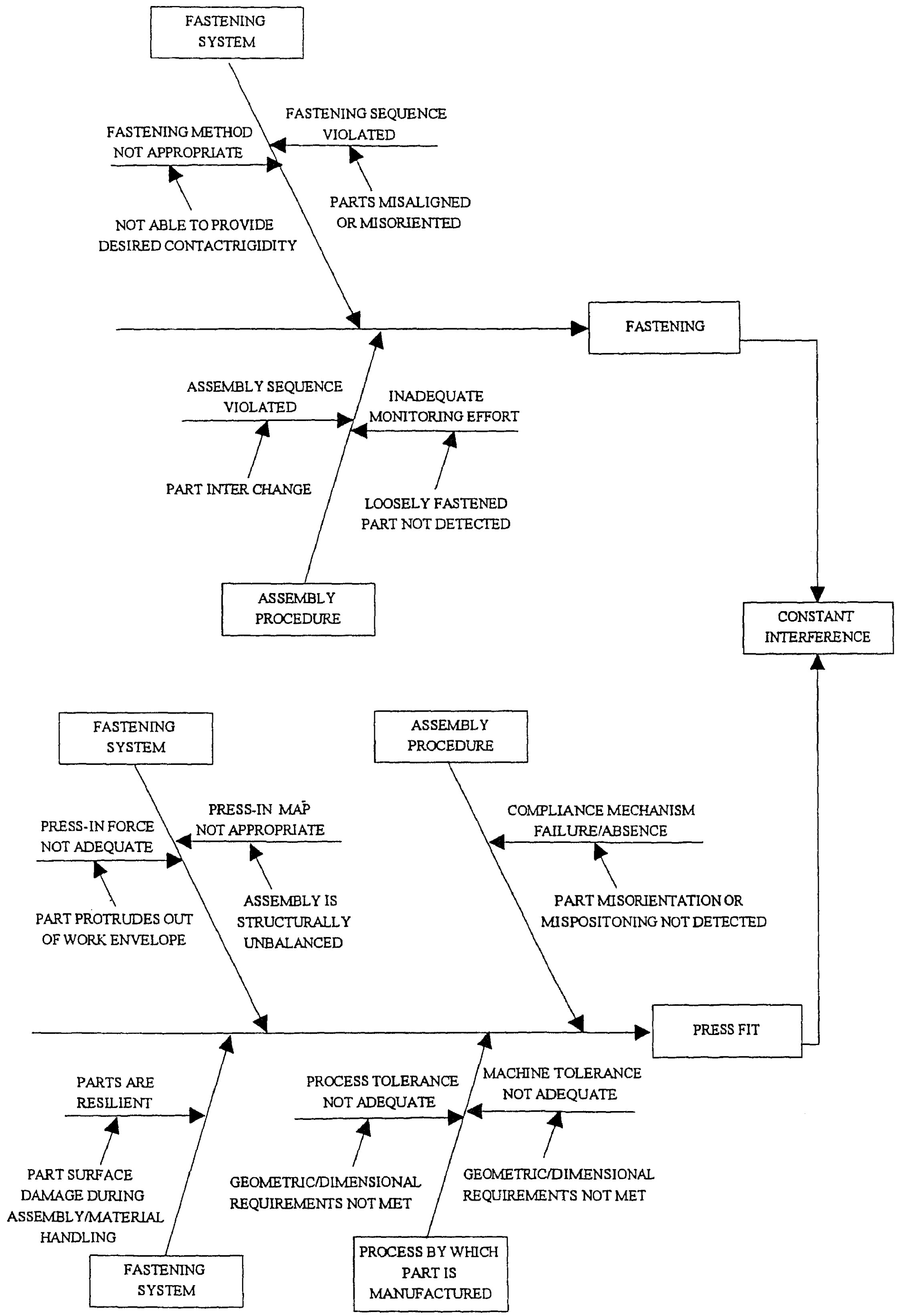


Figure 4.9(continued) Cause - Effect Diagram Constant Interference

4.4 Fastener Related Problems

4.4.1 Loose or Ill Fitting

The success of the assembly is often determined by the precision of parts fitting together. The nature of fit between parts is greatly influenced by the assembly methodology. Fastener related problems addresses to manufacturing quality defects associated with this methodology. One of the most common and damaging among the fastener related problems is loose or ill fitting. Loose or ill fitting is found to have place in all of the earlier identified common assembly processes i.e., insertion, riveting welding, fastening, press-fit, and snap fit.

Geometrical features, material properties, assembly procedure, and process by which part is manufactured are the influencing factors related to loose or ill fitting in insertion. Mating features are determinant in deciding the type of fit between the part and the work. To ensure proper fitting, appropriate clearance value is required. Higher clearance will result in hollow space area between the part and the work and leads to loose fitting. Similarly low clearance hinders the insertion process and causes ill fitting. When the part and the work are made of different materials or have considerably different coefficient of expansions, changes in thermal conditions will evoke conflicting reactions from the assembly components. This can lead to loose or ill fitting. When more than one part is inserted into the work envelope, it is imperative that the stipulated sequence of insertion is adhered to avoid mispositioning of parts. Also adequate monitoring effort is required to prevent part inter change or missing part. Loose or ill fitting can also be a result of nonconformity of the part/work dimensions/geometry to the specifications. Evaluation of process and machine capabilities is a solution to this. For this purpose the tolerance limits of the process and the machine should be accommodative of the specified tolerance range.

Loose or ill fitting in riveted assemblies are caused by inadequacies in the fastening system, assembly procedure and material properties. This specific defect in rivets is characterized by inadequate rivet strength. Rivet strength is a function of number of rivets in the assembly plane and the rivet map. Appropriate structural evaluation has to be conducted to determine the optimum number of rivets and the pattern of its arrangement. Inadequate number of rivets will result in a weak assembly. Similarly inappropriate rivet map will lead to an unbalanced assembly. In either cases, due to the weak binding strength, loose fitting can occur. When there are multiple rivets involved in the assembly, it is important that the established sequence be followed. Violation of sequence can cause misalignment and can lead to ill fitting. Resilient or malleable parts should be avoided in riveted assemblies. Deformation of part surfaces due to rivet impact can impair the fitting. Similar effects are produced due to corrosion/thermal deformation at the rivet site.

Fastening system and assembly procedure are the influencing factors in welding associated with loose or ill fitting. Fitting in welded assemblies is influenced by the capability of the welding method. The method should be able to provide the desired type of contact between the parts. Rigidity of contact is important when determining the fitting of parts. Furthermore rigidity of contact is also dependent on the weld strength. Weld strength is a function of the number of welds and the welding map. To have a structurally balanced assembly, optimum number of weld in the proper pattern is required. Unbalanced assembly will cause loose fitting. Furthermore, remoteness of weld site should be avoided. It is desirable that the welding arm to have adequate access in the weld site. In the absence of which it may not be possible to provide uniform contact area. Adequate monitoring effort is required to avoid surface swapping/part inter change. Mispositioning of part as a result of inadequate fixturing effort will also lead to loose or ill fitting.

Loose or ill fitting in fastened assemblies are influenced by the following factors : fastening system, material properties, assembly procedure, and part inter relationships. Fastener strength is a function of the number of fasteners and the pattern of arrangement in the fastening plane. Measures should be taken to decide on the optimum number of fasteners and its arrangement. The fastening method used should be able to provide the required torque and fastening force. Improper fitting can occur due to mispositioning of parts as a result of mispositioning of parts. Resilient or malleable parts undergo deformation due to fastening force and can cause poor fitting. Similar effects are produced as a result of corrosion or deformation due to temperature changes at the fastening site. Violation of assembly sequence can cause mispositioning while inadequate fixturing force will permit displacement(torsion) of parts while fastening. Accurate evaluation of inter component dimensional conditions and positional relations are required to prevent mispositioning of parts.

The influencing factor that cause loose or ill fitting in press-fits are geometrical features, material properties, and the process by which the part is manufactured. The mating relationship between the part and the work is characterized by the clearance value between the part and the work.. Inappropriate clearance value will influence the fitting relationship. Fitting in press-fits is dependent on the structural properties of the components. Inadequate structural properties will lead to stress relaxation over a period of time and results in loose fitting. Also if the part and the work are made of different materials or have different coefficients of expansions, changes in the thermal conditions of the assembly will evoke different reactions from the assembly components. This can cause loose or ill fitting. The conformance of dimensional/geometric specifications play a significant role in press-fits. Study of the process and machine capabilities in the tolerance perspective will accomplish this objective.

Snap-fits have loose or ill fitting as a result of deficiency in the fastening system, process by which the part is manufactured, and material properties. Parts with high elastic moduli are very resilient and have poor sealing properties. Similarly loose fitting can happen when the parts are not resistant to corrosion, abrasion, solvent, and creep. Lack of such properties can result in damage in the snapping site or deformation in the undercut areas. As discussed in Chapter 3, snap-fits are mostly applicable with plastic and synthetic

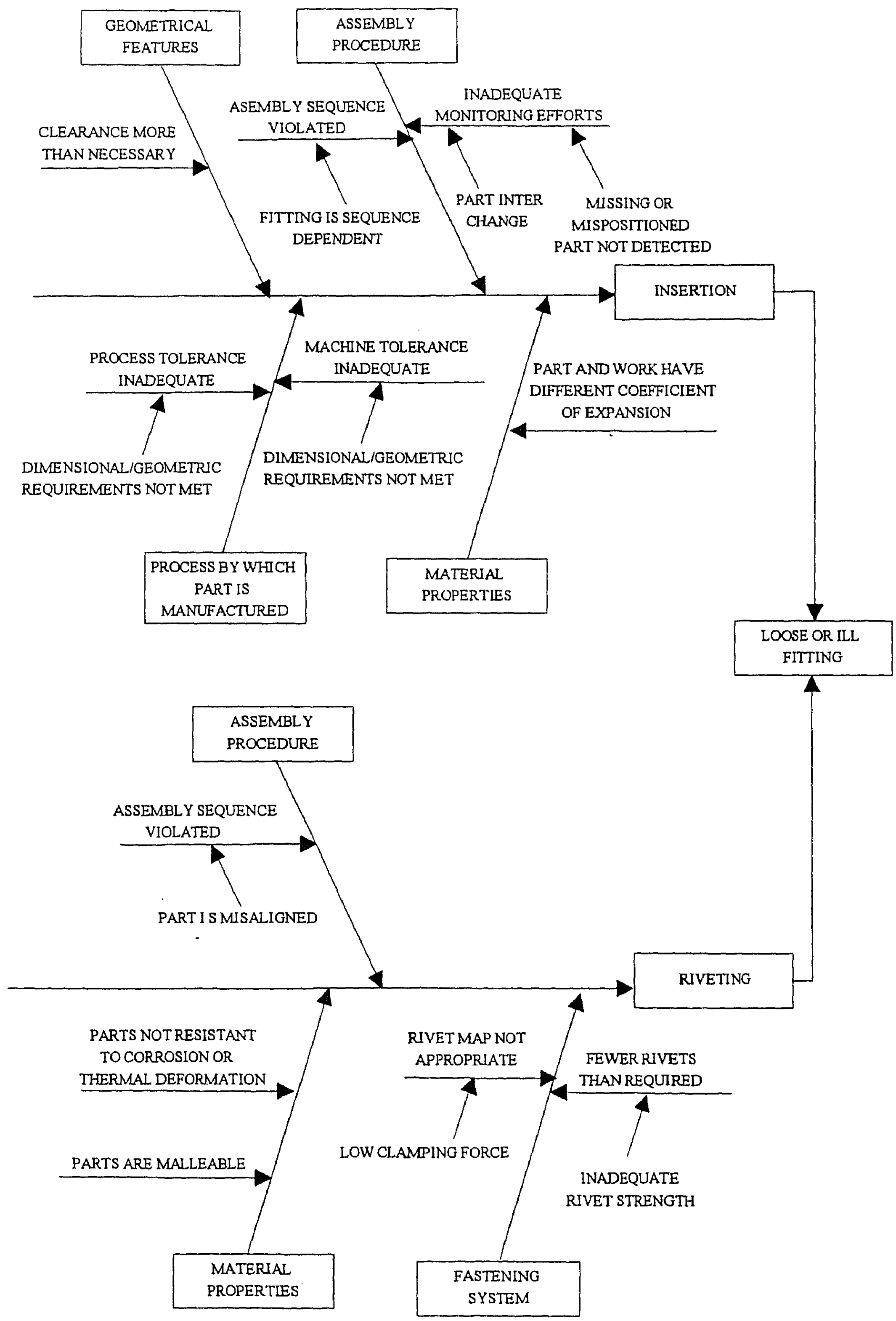


Figure 4.10 Cause - Effect Diagram Loose or ill Fitting

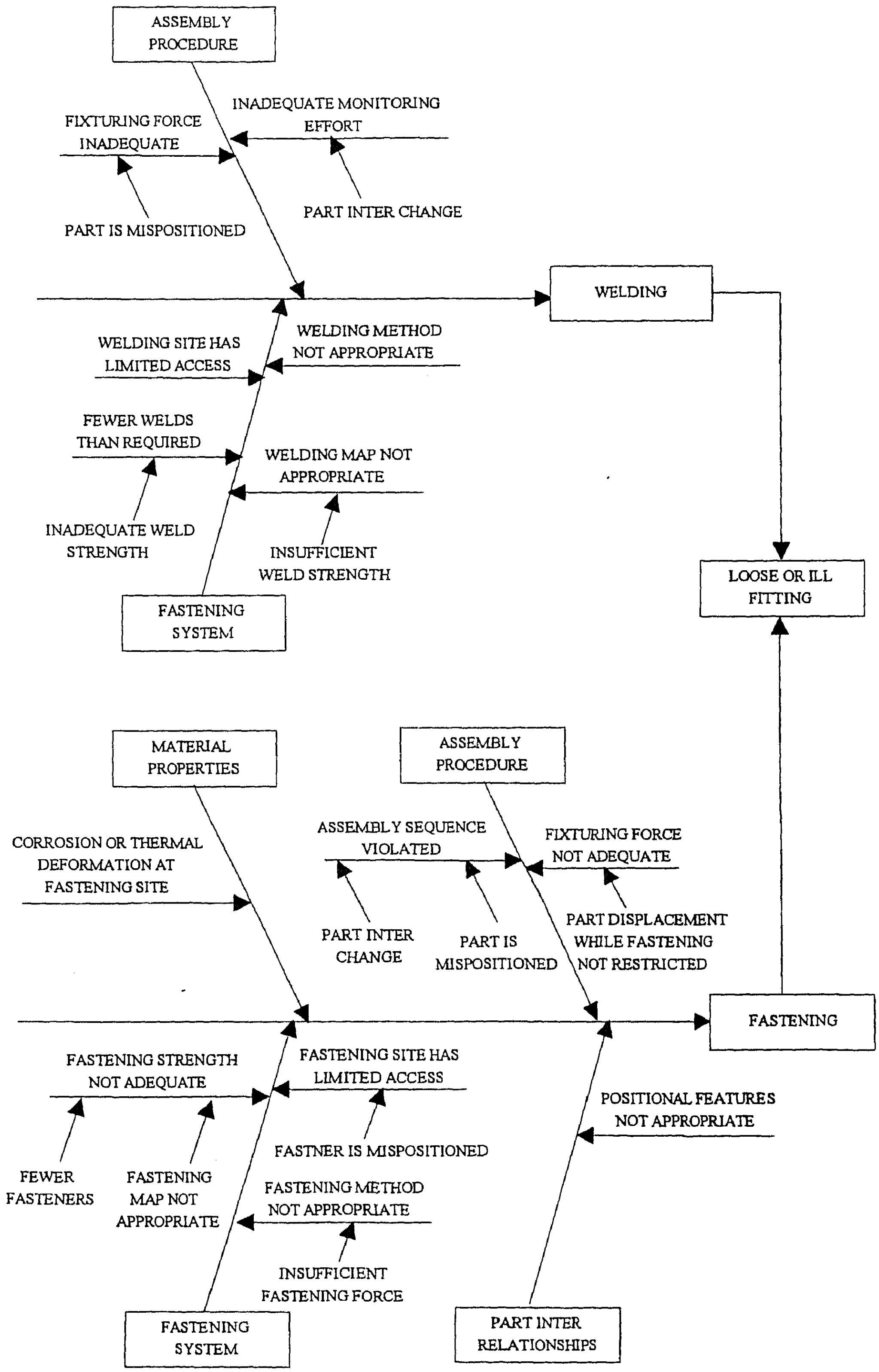


Figure 4.10(continued) Cause - Effect Diagram Losse or ill Fitting

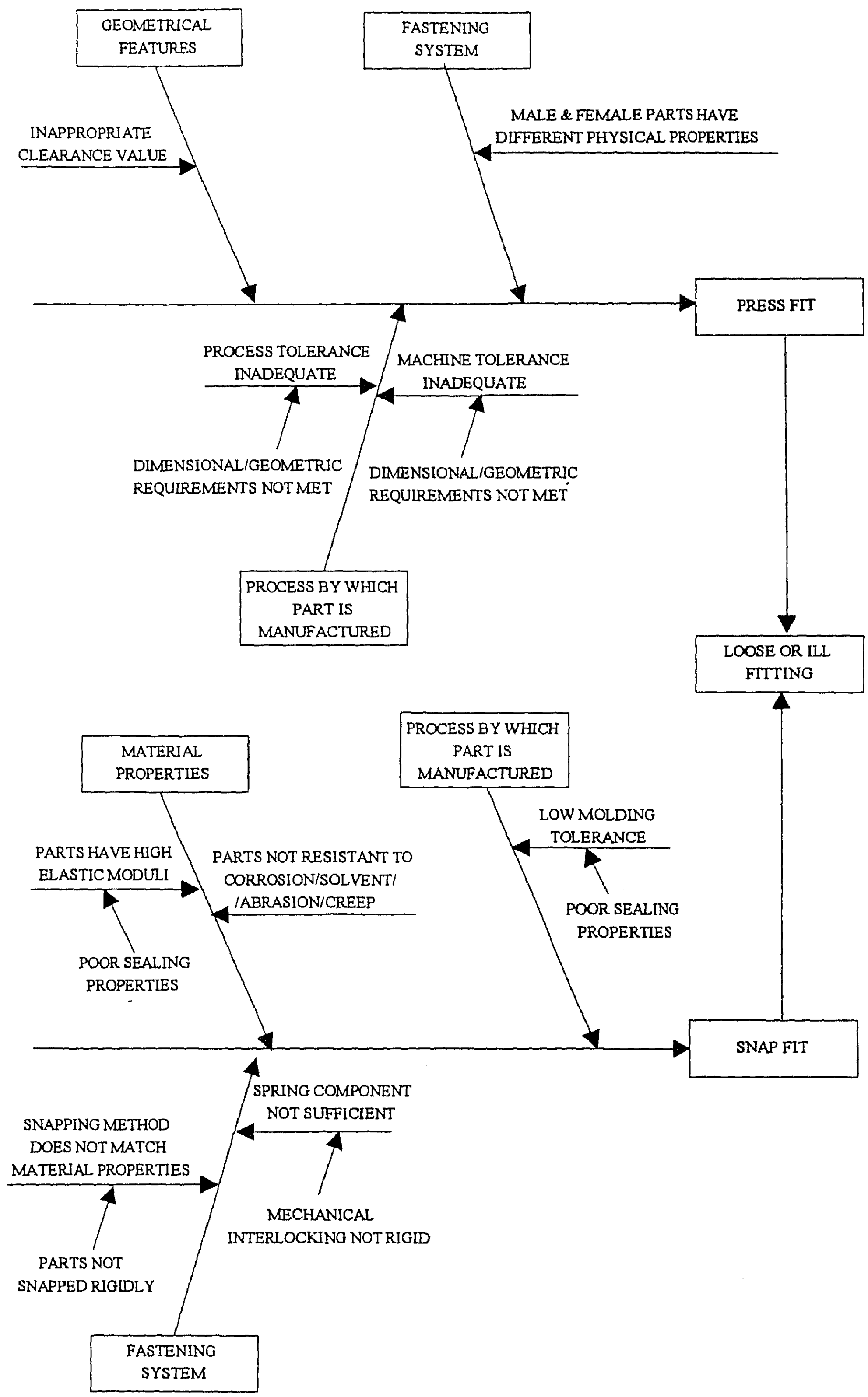


Figure 4.10(continued) Cause - Effect Diagram Loose or ill Fitting

parts which are blow molded to shape. Inadequate molding tolerance will produce parts that do not conform to specifications and can cause loose or ill fitting. Figure 4.9 illustrates the Cause - Effect diagram for loose or ill fitting.

4.4.2 Fracture or Failure

Damage of parts can occur in several stages of manufacturing i.e., material handling, fabrication, assembly etc. Fracture or failure in each of these stages is influenced by several factors. This specific defect has occurrence in the following processes : insertion, riveting, welding, fastening, and press-fit. In the insertion process this is associated with material properties and assembly procedure. When resilient or brittle parts are involved in the insertion process, the insertion force can cause irreparable damage to the part surface. Furthermore part susceptibility to changes in thermal conditions/abrasion can cause similar effects. As pertaining to assembly procedure, when multiple parts are inserted into the work envelope, it is imperative to follow the sequence, since load distribution can be sequence dependent. In that case heavier parts on top of lighter parts can cause fracture or failure.

Material properties, fastening system and assembly procedure are the influencing factors associated with fracture or failure in riveted assemblies. Parts with low rigidity can be sheared due to rivet impact. Similarly rivet force higher than the stipulated value can cause serious damage to part surface. When the rivet site is located in close proximity to the unsupported edges of the part, then the rivet force can cause bending of the part surface and can lead to failure. When multiple parts are riveted together, it is important that the appropriate sequence based on load distribution be identified. Also the fixturing effort has to be adequate to hold parts rigidly while not causing damage to part surface.

Fracture or failure in welding is influenced by material properties and the fastening system. As discussed in Chapter 3, most welding process involve high temperatures to facilitate fusion of parts. Parts not accommodative to such high temperatures will undergo deformation and can cause serious damage to the assembly. The precision of the fastening method play an important role in effecting damage to part surface. As mentioned earlier, due to high temperatures in the weld area, extensive oxidation takes place in the weld site. Adequate/appropriate flux has to be used to avoid blow holes due to oxidation in the metal surface. Blow holes represent weak spots in the weld area and can seriously impair the integrity of the assembly.

Material properties, assembly procedure, and fastening system are the influencing factors causing fracture or failure in fastened assemblies. Resilient or brittle parts can be damaged due to fastening force. Similarly if the fastening force is much higher than the stipulated value or if the assembly is structurally unbalanced due to inappropriate fastening map, fracture or failure can occur. When fastening of several parts are involved, the proper assembly sequence should be identified based on load distribution. This is to avoid damage of lighter parts by heavier ones. Fixtures that avoid part displacement/torsion should not exert a force greater than the rigidity limits of the part. This will prevent deformation of part surfaces.

Fracture or failure in press-fits are influenced by the following factors : geometrical features, material properties, and fastening system. Inadequate clearance between the mating surfaces will require additional press-in force. This can cause damage to the part surface. Similarly parts with low rigidity will undergo deformation even with nominal press-in force. Proper regulatory mechanisms are required to control the pressing force such that its value does not exceed the rigidity limit of the part. Figure 4.10 illustrates the Cause - Effect diagram for fracture or failure.

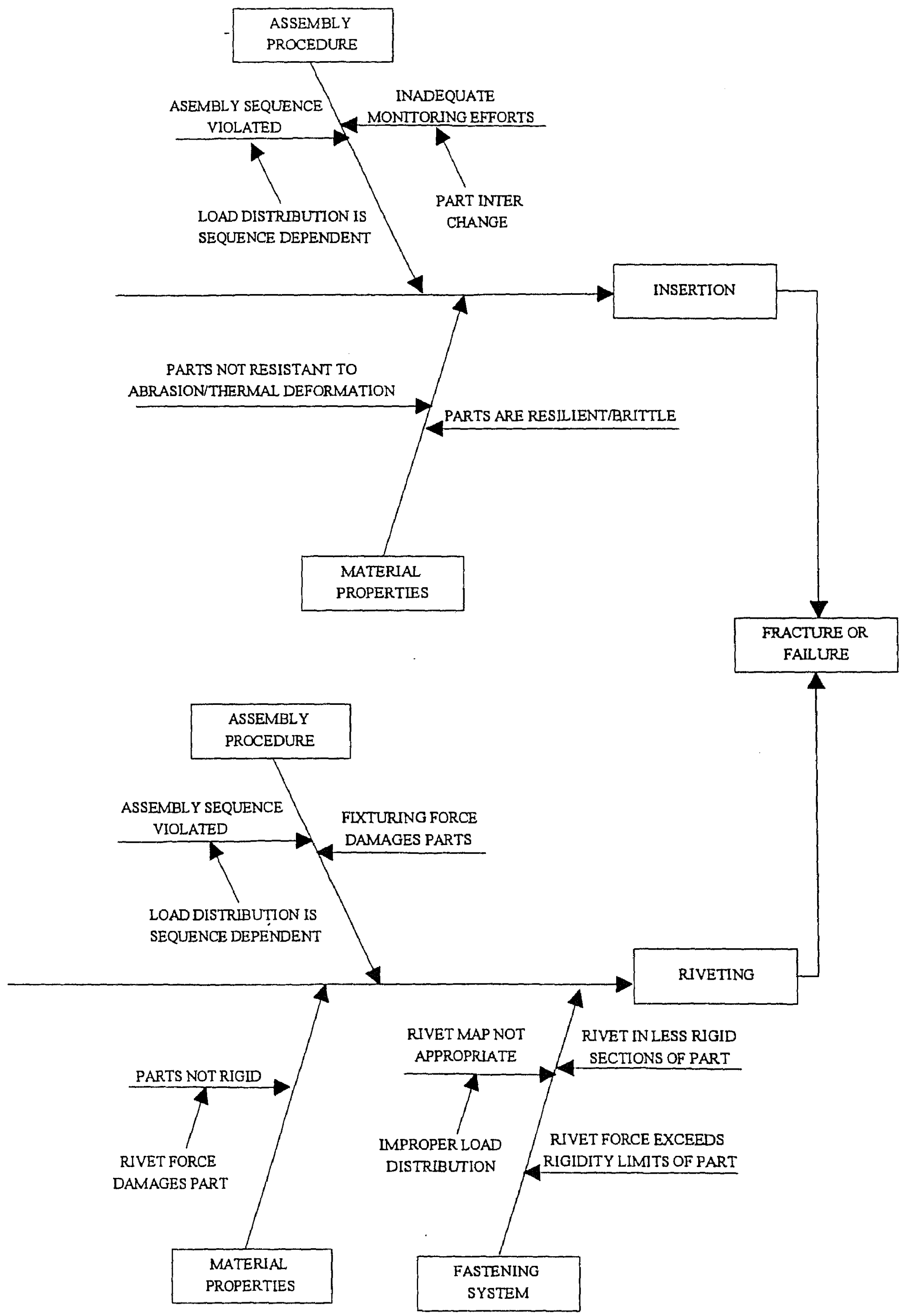


Figure 4.11 Cause - Effect Diagram Fracture or Failure

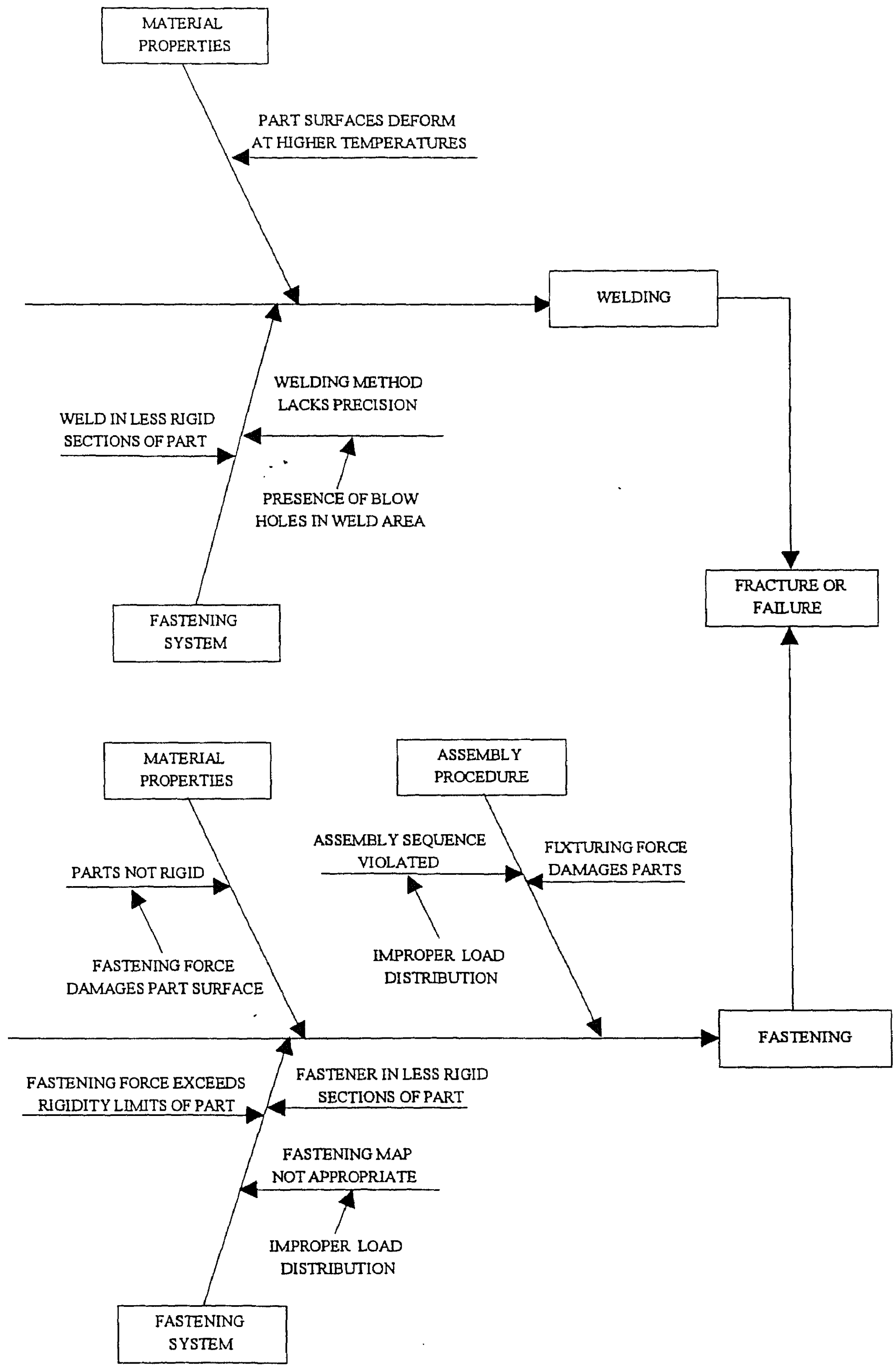


Figure 4.11(continued) Cause - Effect Diagram Fracture or Failure

CHAPTER FIVE

CONCLUSION

5.1 Conclusion and outline of future research

The result of this thesis allows us to draw several conclusions. The proposed structure gives a methodology to evaluate a design and identify its strengths and weaknesses with regard to quality. On the basis of the analysis presented in this thesis work, the Process-Defect matrix is formed(see table 5.1). This matrix helps us to associate the product design with quality defects and the assembly process. Further this helps us to expose the presence/lack of features in the design causing these defects, if the assembly process has been determined earlier.

The Cause-Effect analysis goes a step further in analyzing the process variables of the assembly processes and probes the factors influencing the occurrence of these quality defects. This is a process driven approach starting from the influencing factors and directed towards the specific defect(see figure 2.2) to determine the relevant set of error catalysts. Thus a realistic picture of the various factors and variables associated with the assembly of the product is obtained. Boothroyd and Dewhurst in their research have evaluted the handling and assembly difficulty to estimatate the design efficiency of a product. This approach does not take into consideration the process variables of different assembly processes and the quality defects that might arise during its manufacture to be able to provide an aggregrated estimation. The approach presented in this thesis work will be a valuable concurrent engineering tool by aiding the designer to relate several facets of the product, i.e. geometrical features, material properties, etc., assembly process, and specific defects providing a three dimensional comparison.

Mr. Altaf Yusuf Tamboo in his thesis work has identified error catalysts for missing or misplaces parts and part interference using a defect driven approach and further synthesized and aggregated them into a functionally independent set. This set relates the error catalysts directly with the specific defects and are not dependent on the assembly process. The members of the set were quantified on a zero to one scale signifying their relative likelihood of the occurrence of the defect. It should be noted that all the error catalysts are inherent in the design, and become active or inactive due to specific reasons.

The scope of future research in the Quality Manufacturability Analysis is as follows : Individual values of the error catalysts can be translated into scores for the corresponding specific defect using a stipulated weightage factor. When all the specific defect within each class of defects have assigned values, scores for the class of defects can be computed. Using the QM matrix(see table 5.2) a correlation between the individual components in the design and the scores of the class of defects can be obtained. The values in the matrix signify the magnitude of defect occurrence which can be normalized to get a efficiency score for the design. This approach unlike the Boothroyd and Dewhurst method will be able to identify sources of quality defects and measures to minimize their occurance so as to improve the design efficiency.

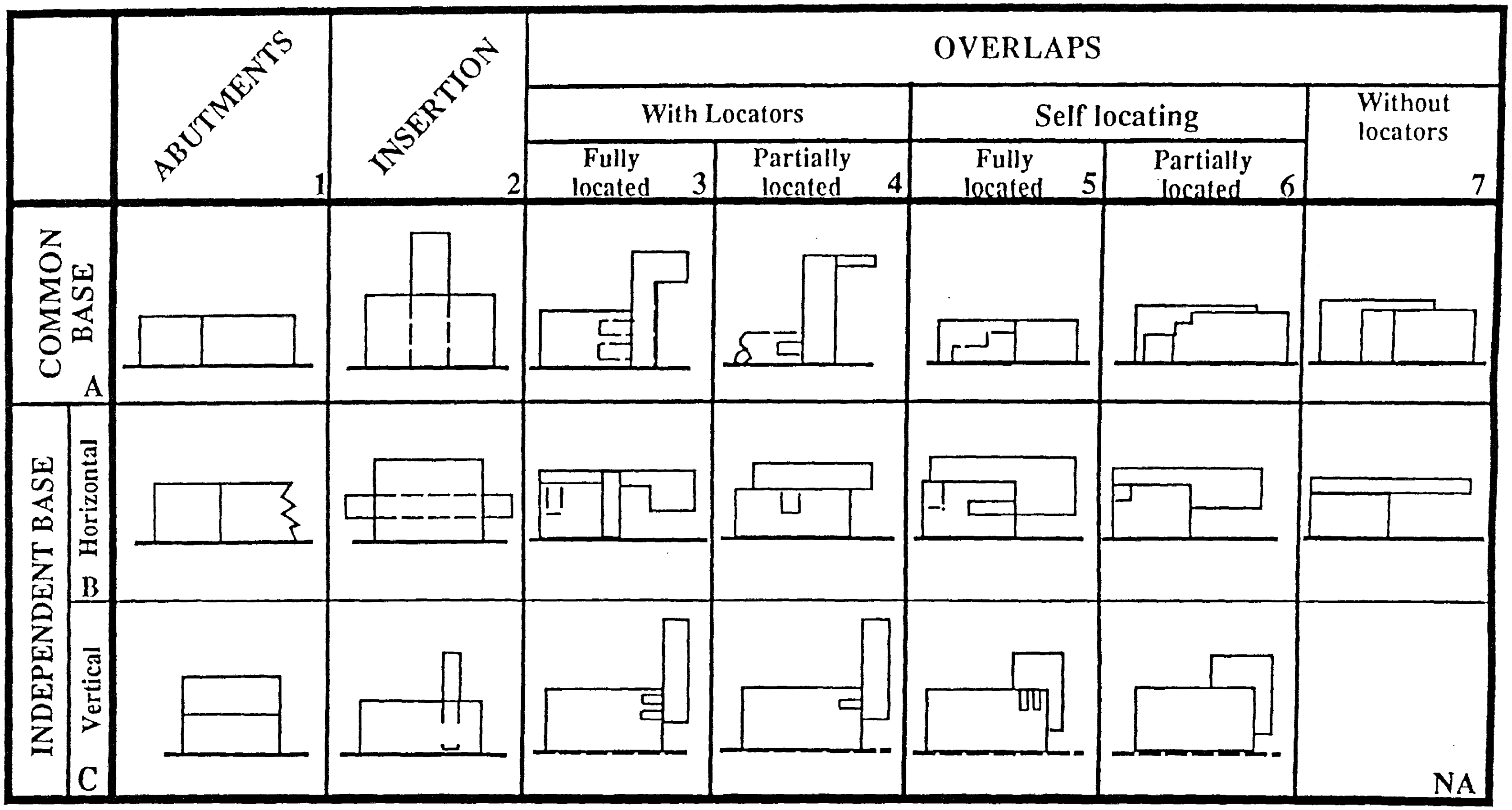
Table 5.1 Process-Defect Matrix

PROCESS / VARIABLES	MISSING PART	AXIAL MISALIGNMENT	ANGULAR MISALIGNMENT	CONSTANT INTERFERENCE	LOOSE OR ILL FITTING	FRACTURE OR FAILURE
INSERTION	Y	Y	Y	-	Y	-
RIVETING	-	Y	-	-	Y	Y
WELDING	-	Y	Y	Y	-	Y
FASTENING	Y	Y	Y	Y	Y	-
PRESSFIT	Y	Y	Y	Y	Y	Y
SNAPFIT	Y	Y	-	-	Y	-

Table 5.2 Quality Manufacturability Matrix

	CD_1	CD_2	CD_3	CD_4	CD_5	CD_6
P_1	0.5	0.9	0.8	0.3	0	1
P_2	0	1	0.3	0	0.7	0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
P_l	C_{1l}	C_{2l}	C_{3l}	C_{4l}	C_{5l}	C_{6l}

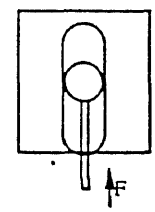
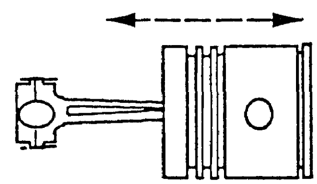
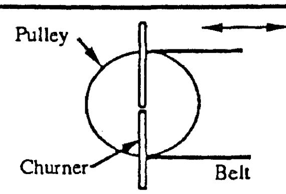
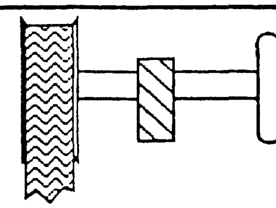
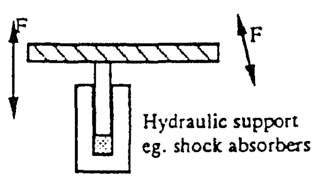
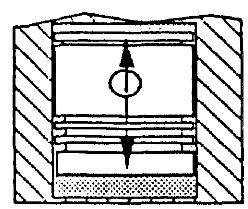
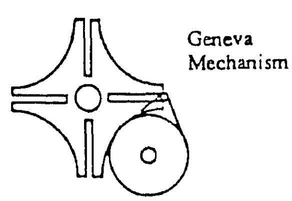
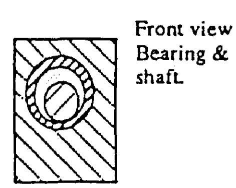
DFQM CLASSIFICATION OF POSITIONAL RELATIONSHIPS.



Note: The `base' means the supporting structure. If the parts have different supports then they are independent base parts and if they share the same support then they are common base. Eg a pulley and it's shaft are independent base because the shaft is supported by bearings and the pulley is supported by the shaft.

Developed by Abhinav Dhar

DFQM CLASSIFICATION OF FUNCTIONAL RELATIONSHIPS

		NON CONTINUOUS N1	CONTINUOUS N2
CONGRUENT MOTION	LINEAR B		
	ROTARY C		
RELATIVE MOTION	LINEAR D		
	ROTARY E		

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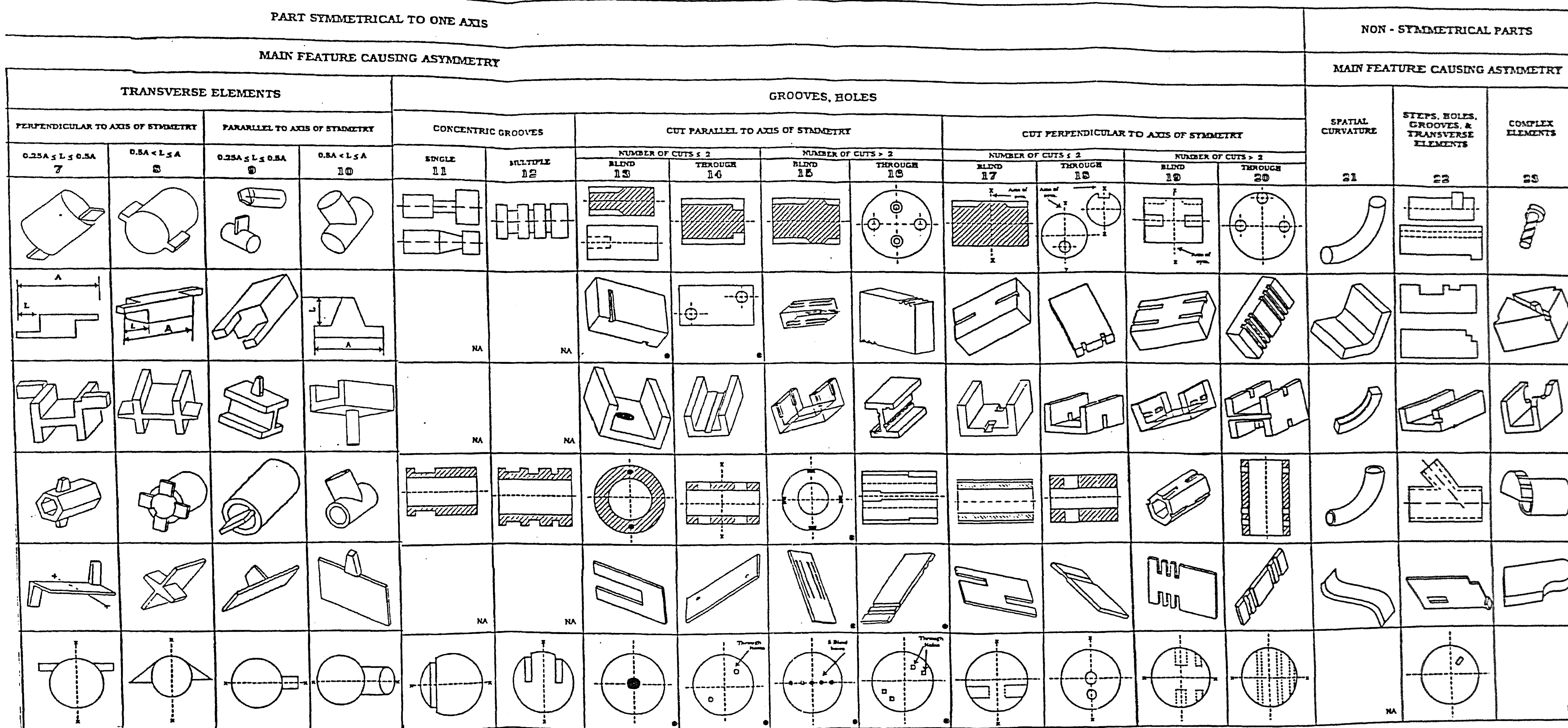
DFQM CLASSIFICATION OF PARTS BY SYMMETRY & GEOMETRY



Parts symmetrical to only one axis of symmetry may contain more than one feature i.e. step, groove, transverse elements. In such cases, the following rules will be applied to uniquely identify the part:

1. The part will be identified with respect to the main feature that causes asymmetry; i.e., if this feature is to be removed, the part will become symmetrical.
2. If rule 1., stated above, does not give a unique identification, the part shall belong to the respective column classifications based on the following order of preference:
   i. Grooves/Hole
   ii. Transverse Elements
   iii. Steps

NOTES :

A Length of the rectangular envelope that would enclose the entire part.

L Length of the rectangular envelope enclosing the transverse element.

⊗ Implies the axis of symmetry is perpendicular to the plane of the paper.

X Indicates the axis of symmetry wherever it is difficult to identify.

● Blind hole/groove

Flat - Shape with a very low thickness as compared to its length and width

Step - Geometric feature that results in a deviation of the silhouette of a part from the silhouette of its envelope.

Transverse Element - External projection other than beta symmetric step that can be seen in a silhouette with length of projection greater than 1/4 of A.

Groove - A cut that results in a deviation of a part from the silhouette of its envelope.

Blind Groove/Hole - Groove/hole which does not cut through the part lengthwise (length of the groove/hole).

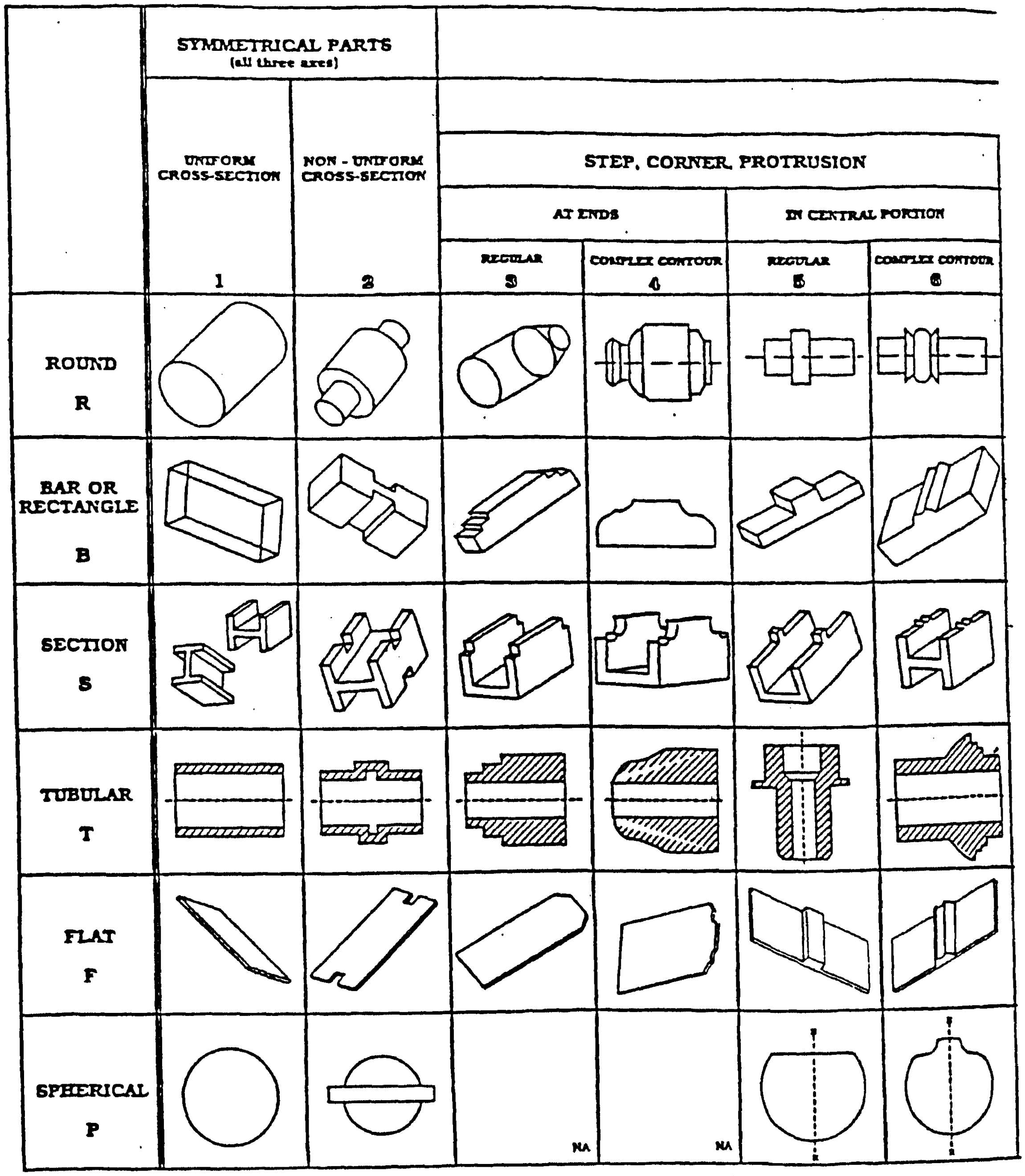
Through Groove/Hole - Groove/hole which cuts through the part lengthwise (length of the groove/hole).

Direction of Groove Cutting - Means the direction in which the length of the groove runs(not the depth of the cut).

Silhouette - The smallest simple geometric outline that encloses the view of a part or its envelope.

Spatial Curvature - A non-symmetrical curved shape.

NA - Not Applicable



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