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Some studies on mechanical assemblies

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Abstract
Assembly is the ultimate process in discrete parts product manufacturing. It is the procedure with the best potential to enhance product improvement techniques and manufacturing strategy. Design and creation of assemblies is intrinsically integrative. Assemblies are technically and commercially important physical products. A company can efficiently improve its prospects and succeed in production through an assembly-driven product realization process. Assembly is additionally the slightest comprehended of manufacturing processes on the grounds that individuals have constantly done it but can't clarify how they do it; it is complex at micro and macro level. This paper aims at presenting some studies on mechanical assemblies and describes the concepts such as mechanical constraints, assembly sequences analyses, assembly workstations, assembly features, assembly cost approach, assembly approach direction, assembly errors, assembly mistakes, assembly modeling in assembly motion, CAD systems, assembly difficulties, Design For Manufacturing (DFM), Design For Assembly (DFA), concurrent engineering, assembly requirements and activities of assembly.

Keywords: Mechanical constraints, design for assembly, assembly features, assembly workstations, assembly sequences analyses

1. Introduction

An assembly is a chain of coordinate frames on parts designed to achieve certain dimensional relationships, called key characteristics (KCs), between some of the parts or between features on those parts. It is necessary to deal with mechanical constraint between parts and how assembly features impose that constraint. The basic need of constraint is to describe the motions that a part can undergo after some of its Degrees of freedom (DOF) have been constrained. A DOF is said to be constrained when it has only single value. Proper constraint is necessary for any design, which means that part should be located in all six degrees of freedoms. Fig 1 shows three axes that represent translation and rotation which is fully constrained of a rigid body.

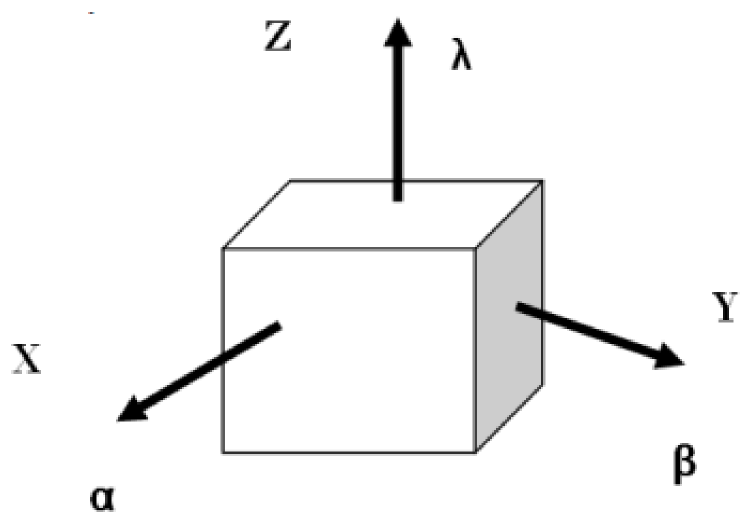


Fig 1: Degrees of freedom of a rigid body

Under-constraint leads to no mating pair of surfaces capable of defining
Over-constraint more than one surface on a part seeks to establish the location of a degree of freedom on a mating part.
The twist matrix intersection in MATLAB form is the process for intersecting several twist matrices that comprises four steps.
Let Twist matrix be T_i, Wrench matrix be W_i
Step1 is accomplished by the MATLAB function called *recip*
W_i = recip(T_i)
Step 2: Collect all the W_i matrices for these features into a matrix called WUWU= [W_1;W_2;…W_n]
Step 3: Obtain the resultant twist matrix from the combined action of all part features
TR=recip(WU)
Step 4 creates an entirely equivalent version of TR called the row –reduced echelon form (rref)
The above said will perform motion and constraint analyses of features. The following situations may occur;

- ✓ The assembly is kinematically constrained, with no over-constrained degrees of freedom and no under-constrained degrees of freedom.
- ✓ Some degrees of freedom may be under-constrained
- ✓ Some degrees of freedom may be over-constrained

Screw theory is used to determine suitable condition. Thus, design and analysis of any assembly can be determined using Screw theory that permits us to represent a precise mathematical way of interactions between two surfaces in contact. Motion analysis describes whether a situation is or is not under-constrained and constraint analysis describes whether a situation is or is not over-constrained. If not both, then it will be neither kinematically constrained nor properly constrained. Assembly components represent a place where two sections join. A few elements perform to hold a section solidly against another, while other features allow some relative movement between the parts.
The main activities of assembly;

- ✓ Marshaling parts in the correct quantity and sequence
- ✓ Shifting parts and partially assembled items
- ✓ Presenting parts or sub-assemblies to the assembly workstations
- ✓ Mating parts to other assemblies
- ✓ Inspecting
- ✓ Testing
- ✓ Documentation of process

The evolution of assembly until around 1940s was largely characterized by increasing the efficiency and speed by industries and later depends upon the division of labor. In late 1960s the robot assembly was introduced and thereon all assembly technologies such as manual, fixed automation and robots use this technique in industries worldwide. Assembly is different from the traditional unit such as fabrication like milling/grinding or welding because it is essentially integrative. It does not bring the parts together but also performs some functions/operations after assembling. Concurrent engineering is the integration of all the different demands of any product that arises in market, finance, engineering, manufacturing, assembly, upgrading, reverse engineering etc. Manufacturing is becoming a huge in product design and to balance their conflict needs, companies constantly revise the old product and further develop new product in order to satisfy the customer needs [1]. Fig. 2 illustrates the steps in designing an assembly system

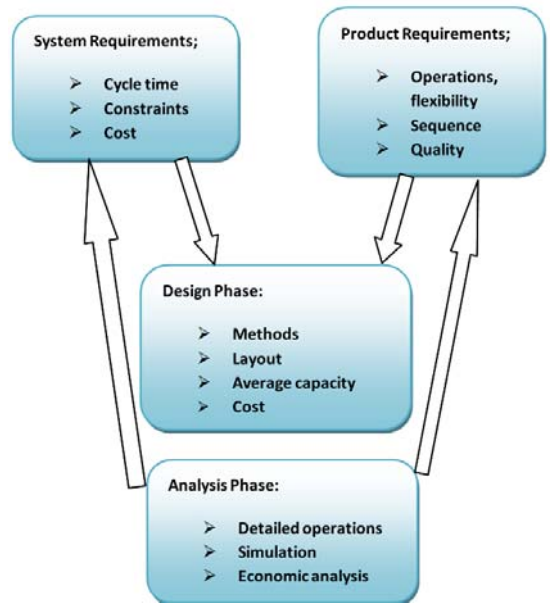


Fig 2: Steps in designing an assembly system

Capacity planning is very much essential for any company, which requires providing the system with the ability to deliver the required number of correct parts or assemblies per hour, day and year. A plant may schedule one or two or three – shift operation. Many factors reduce the actual time available, these factors are grouped into unscheduled downtime, scheduled downtime and process losses. The words “utilization,” “uptime,” “availability,” and “capacity” are often confused by the industrialist, which was clearly said by Peschard [2]. Utilization is the scheduled operating time, Availability is unscheduled downtime, uptime is unscheduled downtime and capacity is process efficiency. Liaison diagram is a line diagram used for an easy understanding of KCs in assemblies. It portrays the chain of parts driving from one side of the gap to the other. Every part in the diagram is a speck and every part-to-part relationship is a line [42]. Fig. 3 shows a liaison diagram for car door panel assembly which contains five sections. Section A joins with part B, C, D, and E. Different associations may be read comparably. Other connections may be read analogously. Liaison diagram also helps for generating feasible sequences in assemblies. The Datum Flow Chain DFC defines the chain of mates between the parts. Thus the liaison diagram includes all the joints between the parts, and then it is clear that the DFC is a subset of the liaison diagram

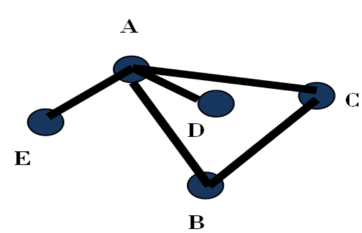


Fig 3: Liaison diagram

2. Assembly workstation design - Major concerns

Workstation and system design are not integrated due to their complexity and several methods are available for doing each step.

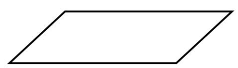
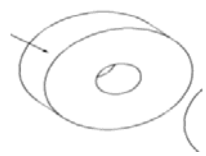
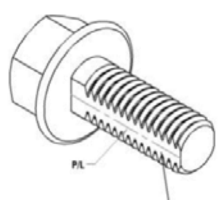
Getting done within the allowed cycle, which is usually short: The work steps that occupy the time include; moving work into the workstation, deciding what to do, getting ready to work, moving to get the part, inserting the part, checking whether the assembly is accomplished properly, recording information and finally passing the assembly out of the station.

Meeting all the assembly requirements: Assembly requirements include; using the correct amount of torque on fasteners, applying lubricant, applying adhesive, keeping the assembly clean and avoiding scratches, dents and other damages.

Avoiding common mistakes: Engineers commit mistakes beyond training and they harass the operators to conceal their mistakes and this deed is called as “poke yoke” in Japan which means mistake proofing

For each operation several phases such as part presentation (feeders, pallets, etc.), reorientation of the receiving part or assembly (jig), acquisition of the part (gripper or tool), transportation of the part to the assembly (robots, gripper, actuator, etc.) and mating of the transported part to the receiving part [3] are required. A shortest path algorithm is used to find a sequence of resource choices of minimum cost that will do all the phases. It is used to find shortest path, the next shortest path and so on. Many such approaches are available to make feasible study [4-5]. Most of the assembly features are made during fabrication; few assembly features carry different design intent and information in their object data and methods. Simple assembly features is shown in Table 1

Table 1: Simple assembly features

S. No	Shape	Geometric Shape	Features	Notations
1.	Plane		Location Orientation Assembly Directions	X, Y, Z α, β, γ + - X, Y, - Z
2.	Bore [pipe]		Location Orientation Diameter Depth Chamfer angle Chamfer depth Assembly Directions	X, Y, Z α, β, γ number number degree number -Z
3.	Threaded Bore		Location Orientation Diameter Depth Chamfer angle Chamfer depth Thread Pitch Thread Class Assembly Directions	X, Y, Z α, β, γ number number degree number Symbol number -Z

From the Table 1, it is clear that the assembly direction for bore and threaded bore has only one approach direction, i.e., -z axis of the local frame, this feature is recommended for robot assembly modeling [6].

3. Assembly modeling in CAD system

Assemblies have been modeled systematically by Lee and Gossard [29], Sodhi and Turner [30], Srikanth and Turner [31] and Roy *et al* [32]. Such methods are intended to capture relative part location and function, and they enable linkage of design to functional analysis methods like kinematics, dynamics, tolerances etc. Gui and Mantyla [33] applied a function-oriented structure model to visualize assemblies and represents them in varying levels of detail. Top-down design of assemblies emphasizes the shift in focus from managing the design of individual parts to managing the design of the entire assembly in terms of mechanical interfaces between parts. Smith [34] proposes eliminating or at least minimizing critical interfaces, rather than part-count reduction in the aircraft’s structural assembly as a means of tumbling costs. He accentuates that, at every spot in the assembly structure, there ought to be only one controlling element that explains location, and everything else should be designed to ‘drape to fit’. Muske [35] describes the application of dimensional management techniques on 747 fuselage sections. He describes a top-down design methodology to systematically translate KCs to critical features on parts and then to choose consistent assembly and fabrication methods.

Shah and Rogers [36] propose an attributed graph model to interactively allocate tolerances, perform tolerance analysis, and validate dimensioning and tolerancing schemes at the part level. Wang and Ozsoy [37] provide a method to generate tolerance chains automatically based on assembly features in one- dimensional assemblies. Shalon *et al* [38] shows how to analyze complex assemblies, including detecting inconsistent tolerancing datums, by adding coordinate frames to assembly features and promulgating the tolerances with the help of 4 X 4 matrices. Zhang and Porchet [39], Tsai and Cutkosky [40] and Soderberg and Johannesson [41] presented the oriented functional relationship graph, which is similar to datum flow chain, including the idea of a root node, propagation of location, checking of constraints, and propagation of tolerances.

4. Assembly sequence analysis

Assembly sequence analysis may be compared based on time, cost, number of reorientations, fixtures and so on. For example, typical large fixtures may cost $3001 each, by cycle time of one minute and extends over a distance of 200 m; for that the entire 200 m must provide fixtures, if 300 fixtures are needed the investment will reach utmost a million dollars. Numerous copies of tool should be purchased for several stations if a different sequence is separated by operation, thus increase the cost of that sequence. Klein found different manual assembly sequence which differs 20% of the total cost for automobile sub-assemblies [7]. Milner, Graves and Whitney [8] discussed a way` to search a diagram of all feasible sequences in conjunction with a path cost calculator. Today many of products exhibit evidence of careful attention to structure and parts consolidation. This can be seen in plastic injection molds which require high quality, exquisite tolerances and complex in features. This is developed in stamping methods as polymer having high strength, low shrinkage and high stability over a long time. It can be noticed in cell phone covers, screw drivers, interior part of automobiles, computers, etc. Design is executed by 3D CAD model and nowadays 3D printer is used widely. Many studies are made in industries about the part count reduction which is nearly 45%. [9-11]

Design for Manufacturing (DFM) and Design For Assembly (DFA) are the concepts which are interrelated. This concept includes functionality, reliability, durability and appearance. There are methods presented for estimating the cost of making cast, molded, stamped and power metal parts [9]. Department representatives from engineering, manufacturing, assembly and field service are commonly called as concurrent engineering. Thus DFM and DFA become automobiles for improving integration of product design and development [17-18]. Ostwald and McLaren [12] give methods for estimating process costs for a variety of processes based on given hourly operating costs for machines. Hu and Poli [13] describes a method for comparing the cost of stamped, molded and assembled parts based on guaranteeing functional equivalence feature-by-feature. Esawi and Ashby [14] describe the Cambridge Process Selector, which searches for good candidate processes based on preliminary part information early in design. Extensive analysis and testing are required to compare different materials and processes for making 'same' part. Virtual environment predicts the assembly problems in recent research in which DFA analyses are found to be best for prediction [15]. Whenever fault occurs in assembly section it leads to increase in cost of assembly. Let us consider the assembly system consisting of one workstation with final test, plus one re-workstation. Reworked assemblies are sent back to the workstation which increase cost and delay in dispatching the products. One of the greatest achievements of lean manufacturing was getting it right the first time [16]. A metric for judging this is to see the size of the rework area at the end of the line; where smaller is better. Size of the rework area has to be normalized to the production rate, so a reasonable metric is the fraction of a shift's production that can fit in this area.

It is important to understand that cost is extremely difficult to quantify. One can look at the checkbook and see what the expenditures are, but it is impossible or difficult to hit upon how the money was actually spent and why. In a manufacturing operation, many costs are distributed or shared because they are associated with support activities. They cannot be directly allocated to a given activity, machine, part, or assembly step. Accounting systems are often designed to help the accounting department balance rather than to help management understand cost structures and make improvements. In general, economics is about deciding how to allocate scarce resources [19]. Comparison of different investment alternatives is needed for cost analysis. It can be determined by Discounting to present value method, Payback period method, Internal rate of return method and Net present value method.

5. Traditional methods of DFA / DFM

The below mentioned are the traditional methods of DFA / DFM.

- ✓ The Boothroyd Method
- ✓ The Hitachi Assemblability Evaluation Method
- ✓ The Hitachi Assembly Evaluation Method
- ✓ The Westinghouse DFA Calculator
- ✓ The Toyota Ergonomic Evaluation Method
- ✓ Sony DFA Methods

In addition to the time estimates provided in [9], one can use standard time handbooks such as described by Zandin [21]. These handbooks use standard work actions like "reach", "grasp", and so on, without taking the design of the part or the assembly operation into account [9] noted that design changes for ease of assembly, like those that reduce part count cannot be made without knowing their impact on the cost of making the part [9]. The Hitachi Assemblability Evaluation Method (AEM) belongs to a class of "points off" methods [22]. In these methods, the "perfect" part gets the maximum score, usually one hundred, and each element of difficulty is assigned a penalty. There are twenty different operational circumstances, each with its own penalty. Each circumstance is accompanied by a simple icon for identification, permitting the method to be applied easily with little training. The AEM is part of a larger suite of tools including the Producibility Evaluation Method (PEM) [23]. This method is applied manually or with the aid of commercially available software. The Hitachi Assembly Reliability Evaluation Method [24] extends the AEM beyond cost and time into the domain of assembly success and product reliability. The impetus for this method arises from several trends; the rise in product liability suits, the introduction of new product and process technologies resulting in production uncertainties and long ramp-up times, shorter product development time resulting in design mistakes, and the degree to which outsourcing makes a manufacturer dependent for quality on the work of other companies.

The Westinghouse DFA Calculator was developed by Sturges [25] for estimating handling and insertion difficult. The calculator is a rotary slide rule which consists of a large disk with a slightly smaller disk and a transparent cursor on each side. Difficulty starts at zero and accumulates as the marked A, B, C and so on. Most DFA methods are designed to evaluate assembly of small parts. In the automobile industry, final assembly of the product involves relatively large and heavy parts. Here, ergonomics, the science of large-scale human work and motion is applicable. Toyota has determined that the weight of a part of the product and the time it must be supported by a worker is a good indicator of physical stress [26]

6. Assembly difficulties, Assembly errors and Assembly mistakes

Difficulty in assemblies takes place in the following items

- ✓ Main function carriers (carriers of important forces, motions, material flows, energy, or information [20]. Conveyors or blockers of fields like electricity or heat; locators of main geometric relationships)
- ✓ Functional supports (user adjustments, user access, seals, lubricants, vents)
- ✓ Geometric supports (brackets, barriers, shields)
- ✓ Ergonomic supports (handles, labels, safety items, indicators, warning, finger guards)
- ✓ Production supports (test points, adjustment points, measurement points, fixturing or gripping surfaces)
- ✓ Fasteners (reversible, irreversible)

The below are steps for analyzing a existing product

- ✓ Understand each part
- ✓ Understand each assembly step
- ✓ Identify high risk areas
- ✓ Identify necessary experiments

Assembly motions can be classified into gross and fine motions. Gross motions generally carry parts from place to place over distances that are large compared to the size of the parts. Fine motions are small compared to the size of the part and occur when parts are touching during actual part mating. In gross motion, errors are generally are found in the positions of stationary parts or the trajectories of moving ones. Because gross motion speeds are high, such errors can cause catastrophic collisions. These errors can be seen by suitable sensors but if they are first detected by touch, then it is too late and the damage will happen before any economically feasible or technically effective response can be mounted. In fine motion, many of the characteristics of errors and feasible responses are reversed from the gross motion case. In many cases, the errors are too small to see with reasonable effort, but they can easily be felt due to the forces and moments they generate. Nevins [18] describes the requirements for successful assembly of 'compliantly supported' rigid parts. Compliantly supported means, by design or accident; the grippers or tooling and / or assembly can distort if necessary in order to accommodate small errors in the trajectory of the parts as they begin to mate. One of the important properties of these compliant supports is that they are passive i.e. they contain no sensors, motors, or other devices. When they move to accommodate relative errors in part positions or orientations, it is because their compliant elements deform under the action of forces and torques that arise between the parts due to these errors. Thus cost and error are related inversely for each resource i.e. given two resources capable of doing the same task; the one that reduces error more or increases it less will cost more. Cost and operating time are also inversely related.

Mistakes are possible in assembly; the most frequent of these are using the wrong part and using a damaged part. No DFA method deals directly with these issues, although general guidelines such as warning may be given. This is sometimes called as 'Assembly Fault Mechanism'. Assembly happens very rapidly, and it is easy to overlook a problem or mistake. Parts need to be designed for easy assembly and to make mistakes hard to commit. Different assembly sequences may make mistake detection or repair easier or more difficult. Team assembly technique is introduced by Volvo. It is a technique in which several operators from division of work get together to form a team. They used this team for a final assembly of cars at Volvo Uddevalla plant. However, quality suffered because operators occasionally forgot one of the many operations during the 90 minutes they spent assembling a car and ultimately assembly plant was closed [27]. The Toyota Production System (TPS) emphasizes assembly mistake reduction by several means, including fool-proofing operations and empowering operators to inspect their own work. Reduction in inventories also makes problems appear rapidly because workers are affected quickly when their buffers run out. It is the reverse of the strategy of using buffers as protection against unforeseen events that leads to mistakes [28]. There is a plenty of opportunities for mistakes while workers take decision. If different versions are built on the same line, some time is needed to gather information about what is oncoming item and what parts and operations it needs. So, designer must take account of a number of issues: getting the work done in time, adhering to the assembly requirements, and avoiding a variety of mistakes.

7. Assembly in 3D printer

3D printer is an additive manufacturing process that is made by fusing or depositing materials such as metal, powders, plastic liquids, ceramics, or even living cells layer by layer to build a 3D object, which is an upcoming technology in recent years. 3D printers are mostly used in various applications starting from toys to bio-printing tissues & organs in medical and dental applications [43]. In general, when we speak about product development, a two dimensional plane is developed to form a three dimensional object as per required shape and size. By the developed technology like 3D printers, a three dimensional object is directly printed when an STL file is imported to the printer. 3D printed materials (parts) are assembled easily when compared to other conventional manufacturing process with good accuracy and precisions in turn require a separate time for assembling the parts to become a finished product [44]. In conventional manufacturing process, we need to fabricate the parts separately and move to sub-assemblies and then to assemblies. On the other hand, 3D printers are also used for printing an assembled product in a single operation which in turn saves the time in assembling the parts with same machining conditions.3D printers can build any components fully assembled.

8. Conclusion

The challenges facing assembly today can be characterized as technical, economic, and managerial. They include design of the products and manufacturing them. From the technical point of view, products are getting more complex. They contain many kinds of technologies, including electronics, mechanics, optics, and occasionally chemistry as well. They are also becoming smaller. Examples include mobile phones, instant cameras, tablets, and other precision devices. Products are also being made in a wide variety of versions and styles. More customers and more different customer needs are being accommodated. Several of these factors drive the economic and managerial challenges. Economic challenges arise because consumers want higher quality and choice at lower price. Low-cost assembly is usually found in low-wage regions of the countries, product specifications travel longer distance between designer, maker, seller, and buyer. The wide variety of technologies forces companies to rely on suppliers for design knowledge, production methods, or even parts and sub-assemblies themselves. Thus, assembly is the process by which parts become products that do useful things. Various studies have been described about the mechanical assemblies. Hope this paper ultimately gives some clear idea for the mechanical engineer about the fundamental concepts of mechanical assemblies.

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