Tolerance Treatments of Pairs and Repeatability in Assembly

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Abstract: In practical applications, statically predetermined pairs are frequently encountered. Designers use them to improve product stiffness. This paper describes a method to reduce the effects of problematic assembly in sliding pairs, which are often statically predetermined. Additionally, it addresses the crucial assembly problem of repetitive accuracy, particularly in assembly line design.

Key-Words: Assembly, Kinematic Couples, Tolerance, Repeated Precision

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1 Introduction

Assembly and assembly procedures are essential elements of production. In many cases, the production process is completed by the assembly, which establishes the critical preconditions for the reliability and quality of the product. Almost every piece of engineering equipment consists of individual components. A characteristic element of assembly processes is the joining of two or more components into sub-assemblies, groups and larger assemblies. A variety of technologies are typically used to join components, including those that provide a direct connection without the need for additional components or materials. In addition to the actual joining, the assembly usually includes other activities such as inspection, commissioning, conservation, transportation of components to the assembly site, and others [6,7].

The importance of assembly in the mechanical engineering industry can be seen from the share of assembly in the labour intensity of mechanical engineering products, which averages 30 to 40 %. Of the total number of employees in manufacturing, about 30 to 50 % are employed in assembly. In high-volume production, the share of assembly labour decreases, which is mainly influenced by the sophistication of the design, a higher degree of mechanisation and automation of the assembly process.

Therefore, it is necessary to actively address the issue of assembly processes and look for ways to reduce the associated costs, e.g. appropriate structural design of the equipment and its division into individual assembly groups and subgroups, selection of simpler connection methods, selection of such beddings that do not require fitting, use of structural elements with a certain degree of freedom, use of standardised and unified components and others [9].

The paper is a contribution to the improvement of the technological construction of product design methodologies in terms of assembly, i.e. the methodologies for the field of DFA (Design for Assembly) [4]. The main objective of improving the assembly process is mostly to reduce the unit cost per product.

A systemic approach can be applied to achieve continual improvement of all components of the assembly system. This paper is aimed at improving the components of assembled product and assembly machines. Researchers all over the world focus mainly on improving the elements of an assembled product in the assembly system. Reduction of e.g. the number of components may lead to a dramatic decrease of the assembly laboriousness' and consequently also the assembly unit cost. The savings can be thus achieved exclusively by brainpower activities while incurring only a minor investment.

Such a methodology is necessary since the well-known methods in this field are characterised by excessive subjectivity of evaluators or by relativeness of the results reflecting the current economic situation.

This paper is aimed at developing an objective method to increase the assembly product quality by using the indicators calculated on the basis of generally accepted laws of geometry, statics, kinematics and dynamics, where assembly quality of construction is assessed by objective indicators such as a number of needed rotators and translators, the necessary volume of rotations and translations, power consumption, optimum dimension and tolerance treatment, as well as other objective indicators permanently associated with the construction of the product, independently from either the evaluators' opinions or the current economic situation in the country.

The objective of this paper is to use the basic sciences (Mathematics, Mechanics, etc.) to generalise the findings from practice through the theoretical examination of the assembly process from manufacturing the parts through their assembly, testing and shipping.

2 Statics in Assembly

The structures are based on pairs, i.e. connections of two bodies to each other. In Fig. 1 we can see a basic overview of the most used engineering pairs, which are: ball joint, rotary sliding pair, rotary pair, sliding pair A, sliding pair B and screw pair.

This problem is also dealt with by prof. Whitney who uses real shapes of solids to represent pairs, but these are not compatible with the theory of statics [13].

Doc. Valentovič recommends the use of spherical models, which are compatible with statics, instead of photographic images and drawings for the illustration of engineering pairs and structures. Such an approach is more convenient because it is clearer and in accordance with statics terminology [11,12].

On (Fig. 1), the diagrams of pairs in the shape of ball models and their brands, which we use when drawing the whole structure, are listed, so that we do not have to create it from ball models in a laborious and complex way.

According to the principle of the spherical model, bodies are considered to be perfectly rigid according to statics, so they meet at single points instead of surfaces.

Fig. 1 illustrates that the ball joint placed in the spherical seat and shown by a spherical model is a three-point joint (it touches the other object at three points); the rotary sliding pair is a four-point pair; the rotary pair is a pair that is prevented from moving (sliding), so it is a five-point pair; sliding pairs A and B are five-point pairs and also screw pair is five-point pair. Next to the spherical models is a suggestion for the use of markers.

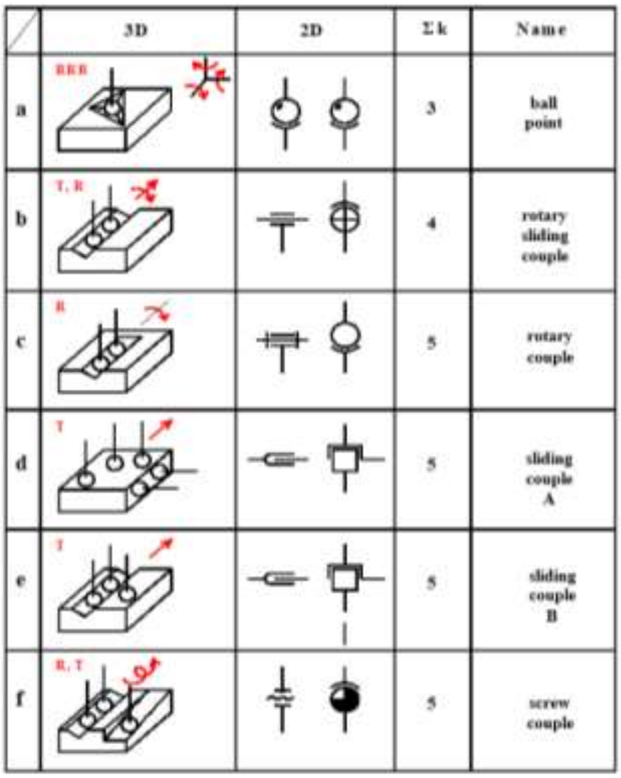

Fig. 1 Basic space movable non-singular couples with proposal for standardisation of signs

Such pairs are correct and can be assembled without problems if they are formed according to the spherical models given above. However, it is important to note that these pairs can also be incorrect. In particular, gear pairs require special attention as they are generally considered to be rolling.

However, this is not true because if a tooth of one wheel engages in the gap of the other wheel at a given axial distance according to the diagram (Fig. 2d), the tooth will only make contact at one point in the gap.

Contact is made at two points only when the wheel is relaxed and pushed into the other wheel, as shown in Fig. 2e.

In particular, it is necessary to be careful about this phenomenon, as the notion is generally used that the gears always form a one-point pair, i.e. rolling.

In the case of rolling couples, it is important to distinguish whether a ball rolls on a plane (Figure 2a), a prism rolls on a plane (Figure 2b) or balls roll in a V-groove (Figure 2c). It is obvious that in each case there is a different number of contact points.

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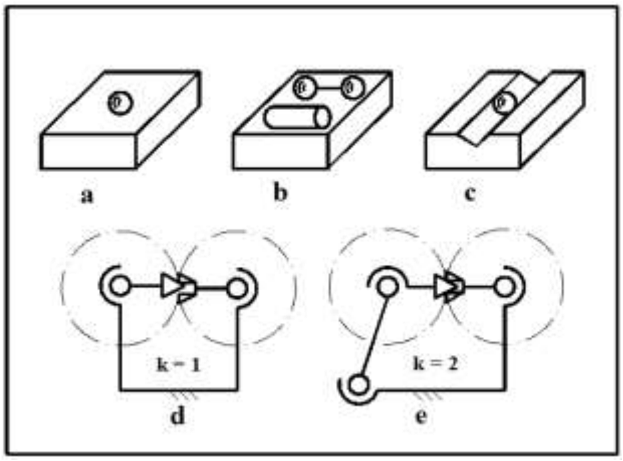

Fig. 2 Movable rolling couples (a, b, c) and tooth couples (d, e)

In practice, the cases of statically predetermined couples are often used by designers to increase product stiffness.

A ball bearing is a classic example of a mechanism that should, theoretically, have a maximum of three balls from a static point of view. However, in reality, more balls are added to increase the stiffness of the bearings.

Fig. 3 shows a column press which is statically predetermined from a structural point of view. When, as in this case, the support moves on two longitudinal rollers, this pair is statically predetermined. According to Grübler – Valentovič´s equation [11, 12], the number of degrees of freedom is minus two.

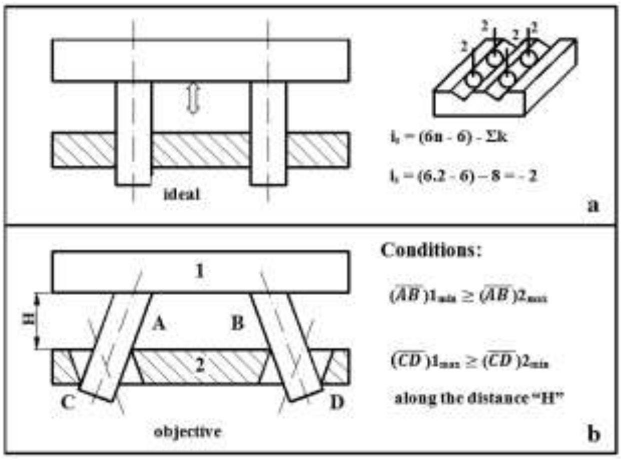

Fig. 3 Toleration treatment of statically redetermined movable couples

Other conditions must also be considered for trouble-free assembly, taking into account the fact that these pairs are not parallel, but divergent or even non-intersecting. In such cases, it is necessary to leave enough space between the pairs so that they can be assembled without problems, even if they are not parallel. However, in this case, we lose some of the stiffness.

Often it is necessary to connect two solids in the assembly process, where it is obvious that it is a statically predetermined kinematic pair.

There are similar cases with flange connections, e.g. connection of a white flange with a black flange that has four pins (Fig. 4a). We must quote both parts so that this assembly is possible under all circumstances.

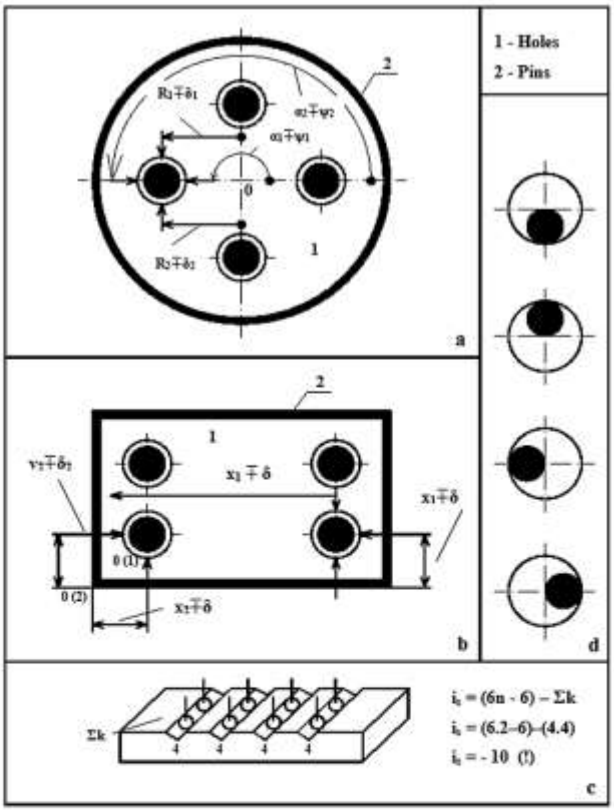

Fig. 4 Assemblability of statically predetermined unmovable couples: a, b - dimension method, c - degrees of freedom number, d - assemblability check

This implies the condition that the pins must be in these holes at all times (Fig. 4d).

This can be achieved by quoting the pins (Fig. 4, pos. 2), and also the holes (Fig. 4, pos. 1), separately from the same base. We shall proceed in the same way with the joints (Fig. 4b).

The advantage of this quotation method is that manufacturing tolerances do not accumulate.

The presented pairs represent very strongly statically predetermined structures, where the expected number of degrees of freedom is one, due to the stability of the displacement.

In fact, according to the formula given in Fig. 4c, we calculate the number of degrees of freedom "is = -10", which implies that the above system is statically

9 times predetermined. However, with proper quotation, a trouble-free assembly can be achieved.

After such processing, it is possible to produce the above components in series with the assurance of trouble-free assembly.

Fig. 5 presents an alternative method for reducing the effects of problematic assembly in very common sliding pairs, which are usually statically predetermined. The sliding pair shown in Fig. 5a is obviously statically predetermined and we can reduce the consequences by first assembling the sliding table with the rods and then attaching them to the base (Fig. 5b). The example in Fig. 5c demonstrates trouble-free assembly with two rotary-sliding pairs (four-point) on one shaft and a single-point pair (touching from the left or right side) on the other shaft. This structure is not statically predetermined but determined, which as we already know will ensure a completely trouble-free assembly.

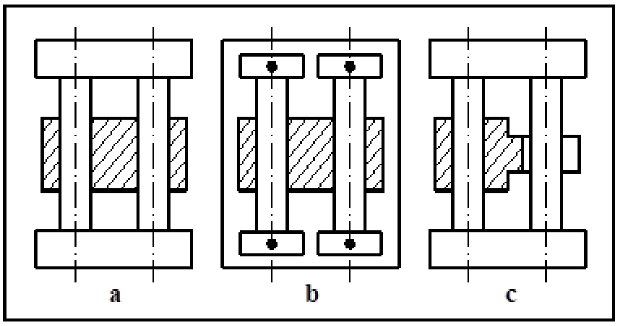

Fig. 5 Assemblability of movable couples [10]
a – statically predetermined structure, b – gradual assembly of statically predetermined structure, c – statically determined structure

If we do not need high precision on our product there is the possibility of using so-called clearance limiters. The principle is shown in Fig. 6.

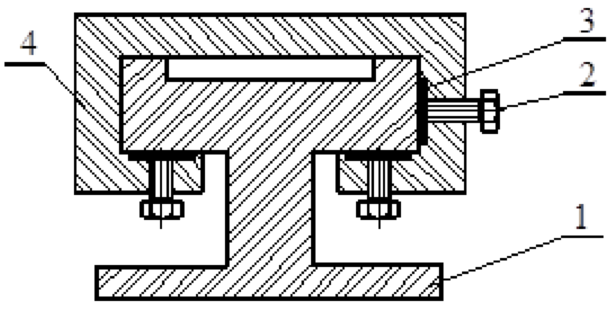

Fig. 6 Assemblability of movable couples.
1 – frame, 2 – screws, 3 – extenders, 4 – bench

3 Statics Repeated Precision of Assembly

Repetitive accuracy is a crucial aspect of assembly, especially in the design of assembly lines. The inaccuracy of the robot inserting the pin into the hole and the hole's position in the drift may cause the pin to fail to insert into the hole. This can happen for two reasons.

The first cause of assembly failure is that, for example, the robot that removes the pins from the pallet has a certain repetitive positioning accuracy (inaccuracy), i.e. when inserting the pins, their spikes are not pointed or positioned at one and the same point (position), but they fill a circle with eccentricity "Ek" (Fig. 7a).

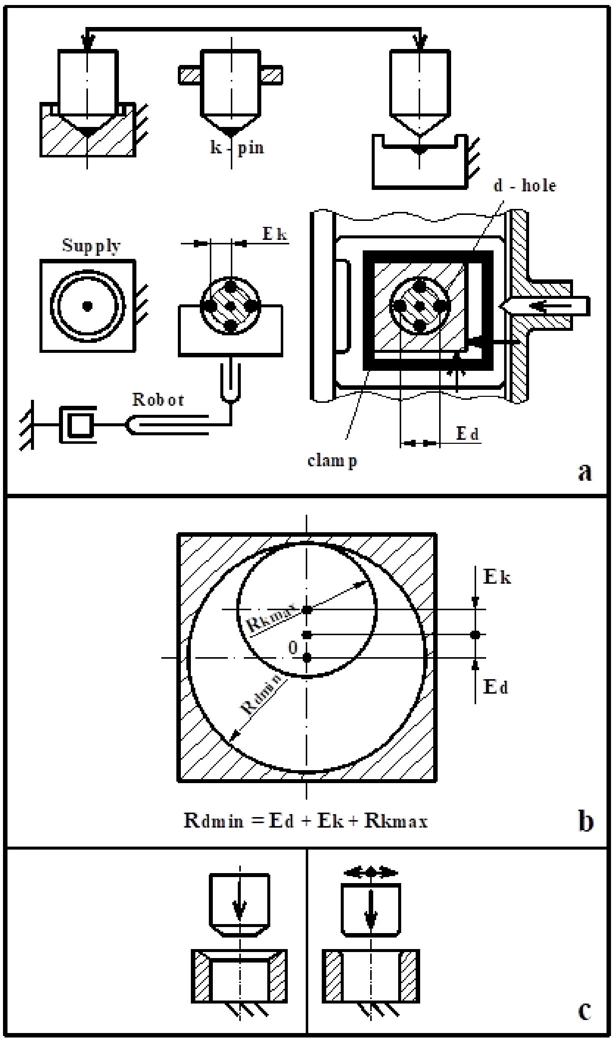

Fig. 7 Repeated accuracy of the robot and clamp increases the probability of the insertion of the pin into the hole [10]
a – robot and clamp, b – conditions of insertion, c – chamfers improve the probability of insertion, d – vibration improves the probability of insertion

The second cause of assembly failure is that the centre of the hole is not always in the same place relative to the machine frame, but may be different in each clamp. This is caused by the inaccuracy of the carrier and the inaccuracy of the clamp, but also by the inaccuracy of the component shape in the clamp (Fig. 7a).

The combination of these causes can lead to inaccuracies that accumulate. It is easy to demonstrate, as shown in Fig. 7b, that if a pin with a maximum radius of R_{kmax} is to fit into a hole, the radius of the hole must be:

$$R_{dmin} = E_d + E_k + R_{kmax} \quad (1)$$

where:
R_{dmin} – minimum radius of opening [mm],
Ed – eccentricity of opening [mm],
Ek – eccentricity of pin [mm],
R_{kmax} – maximum radius of pin [mm].

It is generally known from practice that with this method of assembly, the clearance between the pin and the hole must be disproportionately large. This issue can be avoided by using the necking of both components (Fig. 7c) and trying to use flexibility to get the pin into the hole.

The second option is to place the pin against the hole and make oscillating movements until it catches the hole under slight pressure (Fig. 7d). However, this method is more complicated.

4 Conclusion

We have just proved that the more accurate the assembly line, and therefore the "better quality", the lower the values of Ek and Ed will be. As shown in Figure 7b, the assembly will be trouble-free under this condition:

$$R_{dmin} = E_d + E_k + R_{kmax} \text{ [mm]} \quad (2)$$

or for the diameters:

$$(Ød_{min})/2 = E_d + E_k + (Øk_{max})/2$$

$$Ød_{min} = 2E_d + 2E_k + Øk_{max} \text{ [mm]} \quad (3)$$

After supplying particular values, e.g. $Øk_{max} = 40.1$ mm, $E_k = 0.2$ mm, $E_d = 0.1$mm: $Ød_{min} = 0.2 + 0.4 + 40.1 = 40.7$ [mm].

The clearance (0.7mm) is unacceptable, so we will reduce the hole diameter. In practice, it is often the clearance between the pin and the hole that has to be unreasonably large for this type of assembly.

This issue can be avoided by using the necking of both components (Fig. 7c) and trying to use flexibility to get the pin into the hole.

Another option, but more complicated, is to place the pin against the hole and move it in an oscillating movement until the hole is caught in the pin with a little pressure (Fig. 7d).

If these tasks are to be performed not only by humans but also by machines, these devices must have "artificial sight and feel", but these systems are then very complex, which leads to an increase in the cost of the assembly process.

The paper is a contribution to the improvement of the assembly methods in the field of technological construction of product design in terms of assembly [5, 8] or in the area of methodologies known as DFA (Design for Assembly) [3].

The general objective of improving the assembly process is mostly a reduction of the unit cost per product.

Reduction of the number of components may lead to a dramatic decrease of the assembly laboriousness' and consequently also of the assembly unit cost. The savings can be thus achieved exclusively by brainpower activities while incurring only a minor investment.

The well-known methods in this field are however characterised by excessive subjectivity of evaluators, or by relativity of the results related to the current economic situation.

This paper was therefore aimed at developing an objective methodology to increase the assembly product quality by using the indicators calculated on the basis of generally accepted laws of geometry, statics, kinematics and dynamics, where assembly quality of construction is assessed by objective indicators such as a number of required rotators and translators, the necessary volume of rotations and translations, power consumption, optimum dimension and tolerance treatment, as well as other objective indicators permanently associated with the construction of the product, independently from either the evaluators' opinions or the current economic situation in the country.

The methodology is not only a tool for evaluation; it also reveals the causes of so-called "troublesome assembly", indicates the ways of problem elimination and reduces the overall complexity and laboriousness of assembly work.

This does not however mean that the known methodologies [1, 2] should be ignored.

Further research will aim to make the effort to improve the methods known under the abbreviation of the DFA (Design for Assembly) and verification of the methodology with Artificial Intelligence.

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