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ANALYSIS OF THE MOST COMMON FAILURES OF GEARS IN UNIVERSAL GEAR REDUCERS

Milan RACKOV, Siniša KUZMANOVIĆ

University of Novi Sad, Faculty of Technical Sciences, SERBIA

Abstract:
Universal gear reducers are important mechanisms of every machine and production line and they are often used in all branches of mechanical engineering. Regular work and quality of many machines depend on reliability and quality of gear reducers. Thus, the gears, as the most important elements of every gear reducer, have to be properly calculated, dimensioned and designed. However, beside all this precautions, gear failures can happened due to occurring of overloads, manufacturing and material failures of gears and other different unpredicted influences. Failures can occur suddenly or as a gradually teeth wearing off. This paper will give a review of the most common failures of gears in gear reducers and also some measures for their prevention.

Key words:
gear reducers, gears, breakdowns, gear failures

1. INTRODUCTION

Mechanical power transmission units are among the oldest mechanisms that mankind invented and they are certainly the most often used mechanisms in mechanical engineering and machine industry today.

Today, mechanical power transmission devices are produced in large series of millions specimens as special units (for example in the frame of automotive industry, railway machine industry, constructing machines industry, etc.), and as universal units (for all fields of mechanical engineering, usually with electric motor mounted, so called motor gear units or driving units). Application of mechanical power transmission units is certainly wide today, and it can be concluded that there is no industry branch that does not need any type of gear unit. Universal gear units are usually applied in mines, thermo and hydro plants, food industry, constructing materials industry, municipal service companies, etc.).

By their proper operating, mechanical gear units, as an important component of driving system, have significant influence on reliability of overall system. However, breakdowns of gear units can also happen, and thus they could be the cause of unplanned production interrupts. Although all conditions for proper operating are ensured by their construction, their sudden breakdowns yet occur. The reason for that can be failure of one or several elements, which causes irregular operating, or momentary break of gear unit operating.

Because of its function, to transfer mechanical energy from motor to some working machine, breakdown of mechanical gear unit refers to momentary breakdown of overall system, interrupt of its operating and production stop, which can cause large economic losses for users of gear units.

2. BREAKDOWNS OF GEAR REDUCERS AND THEIR CAUSES

In order to provide reliable and quality operating of gear units and systems that contain gear units, during whole projected operating life, it is necessary to analyze in detail all characteristics of proper operating of gear unit, their operating characteristics with different failures, as well as reasons for occurring of accidental and breakdown situations.

This paper analyses different causes and failures of gears inside of motor gear reducer. Reducing possibility of failures occurrence is also considered by the authors of this paper, using particular example of gear reducer made by Sever-Subotica with axis height 90 mm. Possibility of failures reducing is analyzed prevailing due to constructional malfunctions which are the most usual technical causes of gear units breakdowns. As a result of this analysis, modified design solution is recommended, so it can carry projected loading without breakdowns.

The most of breakdowns of gear reducers do not happen immediately, but gradually, because some period of time is necessary to pass, so that all conditions requisited for breakdown occurrence are created. Failures of gear reducer components usually occur due to design defects, material defects, manufacturing defects and exploitation defects. Failure occurrence, i.e. occurrence of reduced operating capability, can be manifested by different intensity. Increasing failure intensity, in one moment reducer will turn to the breakdown state. Gear reducer breakdowns can be considered from different points of view, so that they can be classified according to several criteria (Fig. 1) [1].

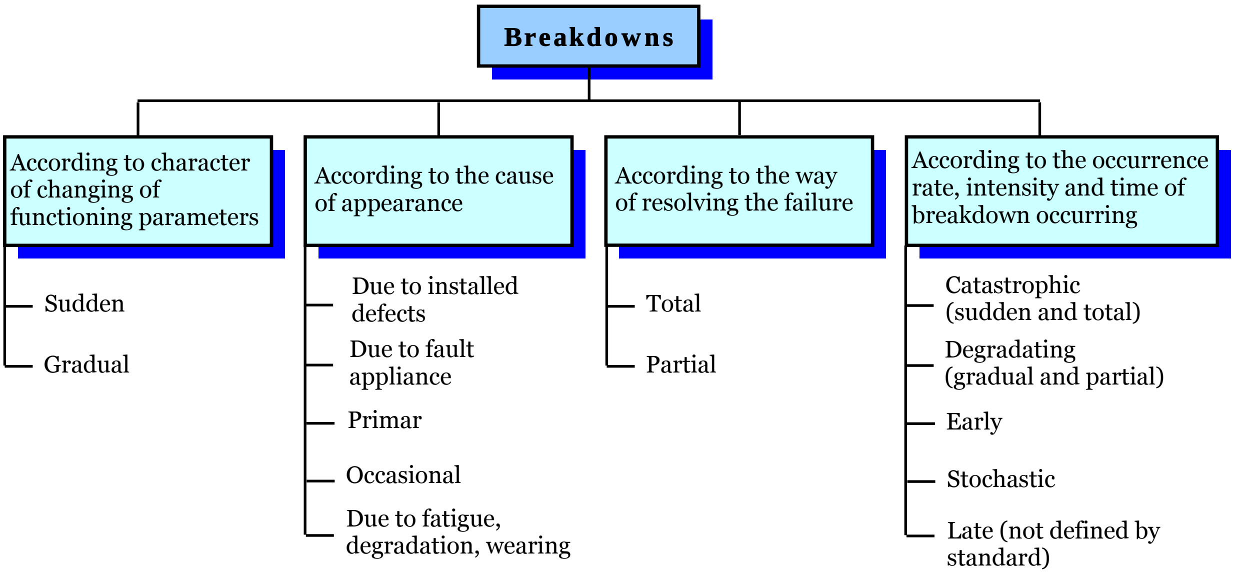


Figure 1. Schematic review of breakdown classification of gear reducer [1]

According to changing of functioning parameters of gear reducers, breakdowns can be sudden or gradual (late). Causes of sudden breakdowns have stochastic, unsteady character and they can not be predicted (for example connection breaking, fractures, processes of concentric wearing, etc.). Gradual breakdowns can be predicted by its intensity and direction (surfaces wearing processes, material degradation, corrosion processes, weakening of connections between reducer components, etc.).

According to cause, breakdowns can occur due to installed defects, due to fault appliance, due to fatigue, degradation or material wearing, and also can be primar and occasional.

According to breakdowns resolving, there are total and partial breakdowns. Total breakdowns result with totally loss of operating capability of reducer and they are resolved by replacing part that has broken down. These breakdowns are usually breakings and fractures, and this kind of breakdown can cause breakdown of other reducer components. Partial breakdowns occur as a result of disturbance in operating process, when only partial operating capability of reducer is lost. This kind of breakdowns can be failures of sealers and washers, oil leaking, higher vibration due to fault mounting or improper installation, and they are resolving by certain maintenance procedures.

According to speed, intensity and time of occurring, breakdowns can be catastrophic, degradating, early, stochactic and late. Catastrophic breakdowns are, in the same time, sudden and total, and their characteristic is large economic and material damage. Degradating breakdowns are gradual and partial in the same time. Early breakdowns of reducer occur in the period of running in. Stochastic breakdowns occur during regular exploitation, and late breakdowns intensively occur after period of projected operating life.

Breakdowns of gear reducers can happen due to technical defects, organizational faults and unsatisfactory competence and personnel training. Nevertheless, gear reducers usually fail due to technical malfunctions, where especially belong design, technological and exploitation causes (Fig. 2). 12% breakdowns, of overall breakdowns amount, are caused by mistakes and defects made during the process of constructing and design [1]. This paper deals with possibility of intensity reducing this kind of design failures to minimum.

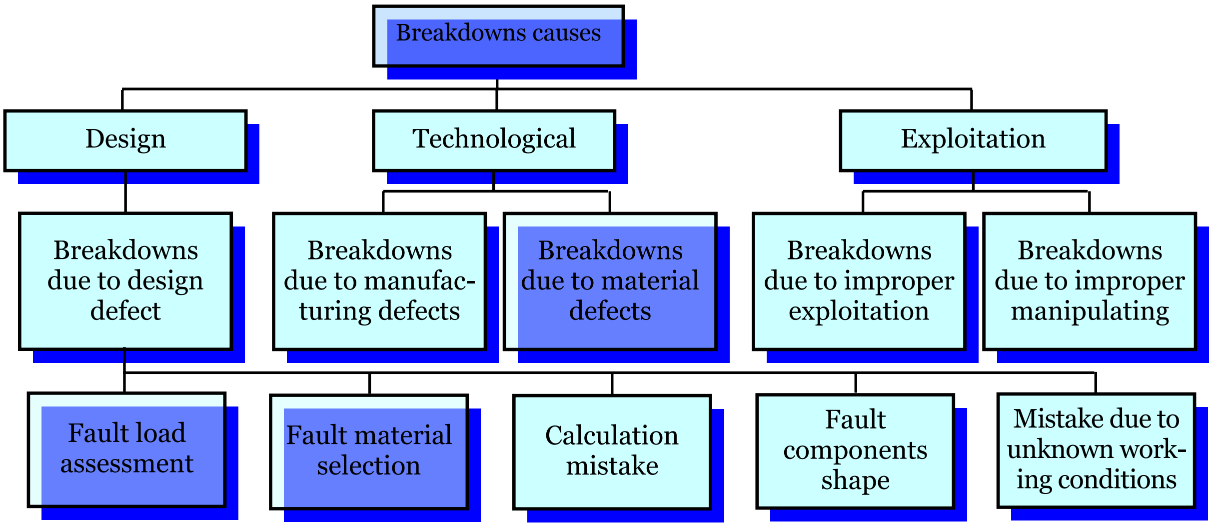


Figure 2. Causes of breakdowns occurrence

Considering breakdowns during exploitation and their causes, three characteristic periods can be noticed. In the beginning of exploitation, early breakdowns occur as a result of latent design and technological malfunctions. In further reducer exploitation, stochastic breakdowns can occur due to overloadings. After long period of exploitation, amplified (late) breakdowns occur as a result of fatigue, corrosion and aging. Causes of breakdowns for all these three domains are different, so that measures for their reducing (increasing reducer reliability) are different for all of these three time range. Frequency of all these breakdowns is directly proportional to undertaken activities for resolving design and technological causes of breakdowns during period of reducer development. Therefore, it is important to detect and remove as much causes as possible in this period, especially those latent defects and causes which could cause later, during exploitation, premature breakdowns and reducing projected operating life of gear reducer.

3. GEAR FAILURES

60% of gear reducer breakdowns happen due to gear failures [2], which means that quality and reliability of gears are very important for proper operating of reducer. When transfer load from pinion to gear wheel, teeth flanks relatively move between each other by sliding and rolling. Thus, depending on torque value, teeth flanks are exposed to smaller or bigger contact pressures with sliding at the same time, and tooth dedendum is exposed to flexion, too. In these conditions, depending on torque and operating regime, different failures of gears can occur, i.e. breakdowns can be manifested in different ways. Failures that occur on gear teeth, are various and can be, according to ISO 10825, classified as: surface disturbances, scuffing, permanent deformations, surface fatigue phenomena, fissures and cracks and tooth breakage (Fig. 3).

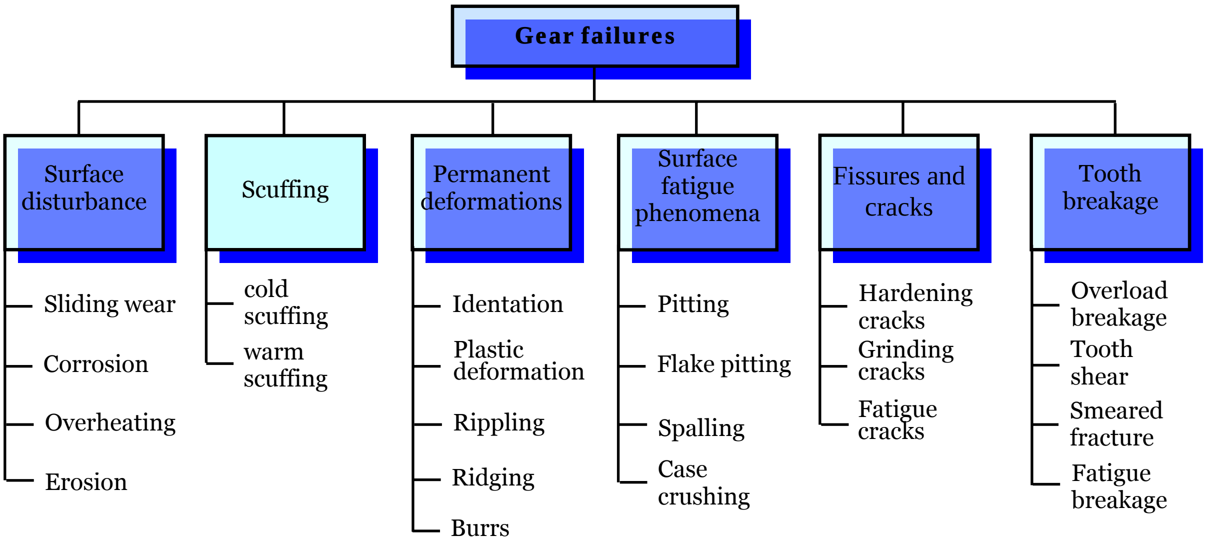
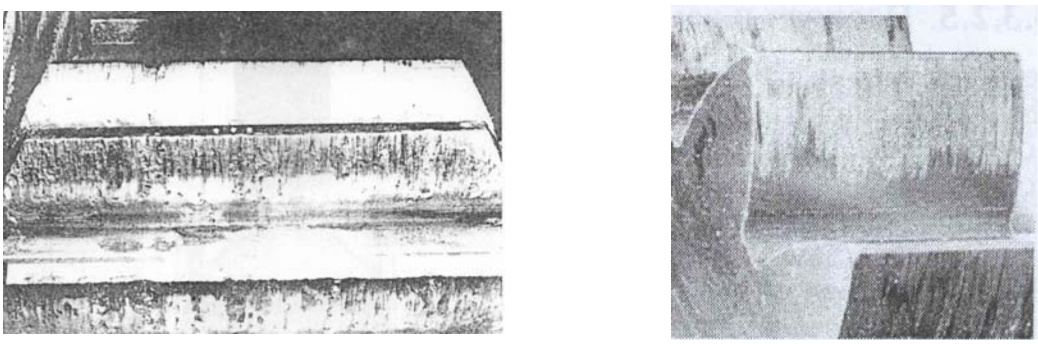


Figure 3. Classification of gear failures according to ISO 10825 [5]

Indications of surface disturbances comprise failures of gear teeth, such as: sliding wear (Fig. 4-a), corrosion (Fig. 4-b), overheating (Fig. 4-c), as well as some types of erosion, but they are not result of fatigue process.

a *b* *c*

Figure 4. Types of surface failures of gear teeth
(a- sliding wear; b - corrosion; c - overheating)

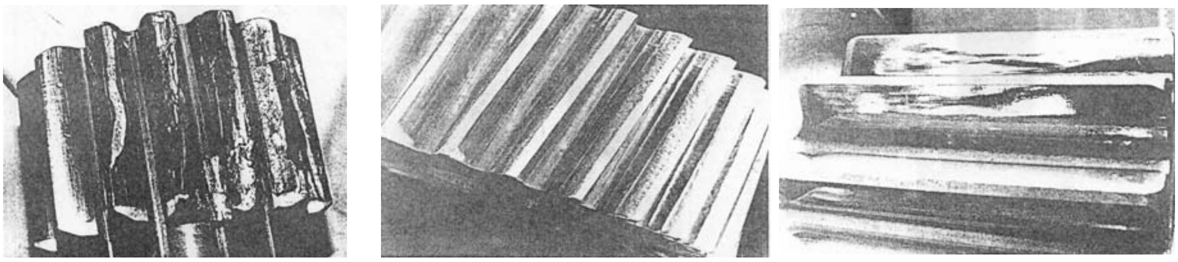


a *b*

Figure 5. Scuffing of gear teeth
(a- cold scuffing; b - warm scuffing)

Scuffing of gear teeth (Fig. 5) occurs due to great pressure loads and high sliding velocities. It represents drastic kind of teeth failure. Scuffing occurs suuddenly, when lubricant film between the tooth flanks is disrupted. This can lead to localized welding of the tooth flanks with transfer of material.

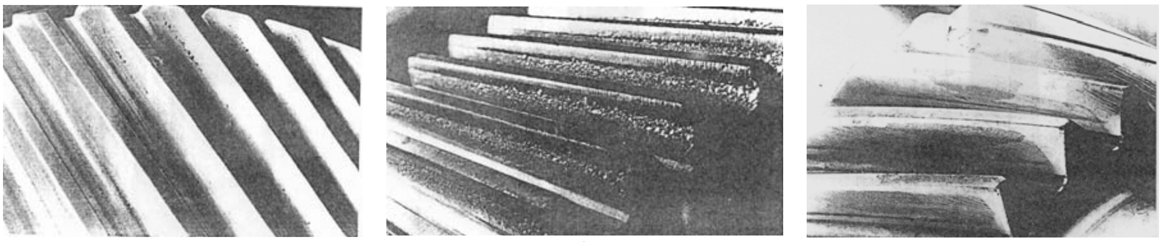
Permanent deformations of gear teeth are failures of tooth profile. They occur due to great torques, when material of gear or heat treatment of gear are not properly matched with working conditions, or some filthiness or foreign bodies are present in lubricant. This kind of failure usually comprises: identation (Fig. 6-a), plastic deformations (Fig. 6-b) and rippling (Fig. 6-c).



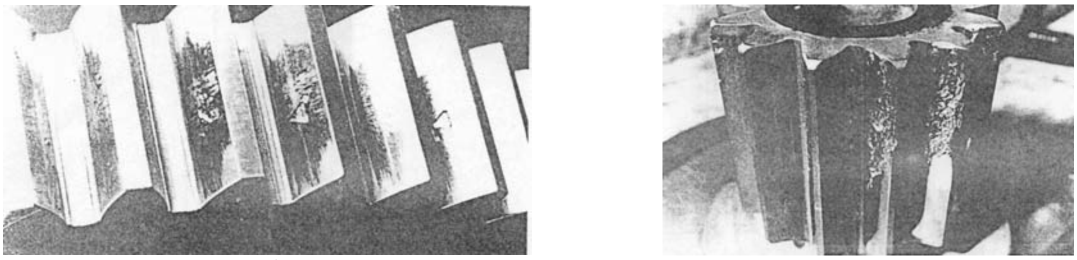
a *b* *c*

Figure 6. Permanent deformations of gear teeth
(a- identation; b - plastic deformations; c - rippling)

Surface fatigue phenomena occur because of material damage due to surface and subsurface stresses produced by the repeated application of forces. It is characterized by removal of metal and the formation of cavities. Pitting is one of the most usual fatigue surface failures. It occurs in the presence of rolling or mixed rolling and sliding contacts. Particles break out of affected areas leaving surfaces pock-marked with scattered holes. There are several kinds of pitting: initial pitting (Fig. 7-a), progressive pitting (Fig. 7-b), micropitting (Fig. 7-c), flake pitting (Fig. 7-d) and progressive macropitting, called spalling (Fig. 7-e).



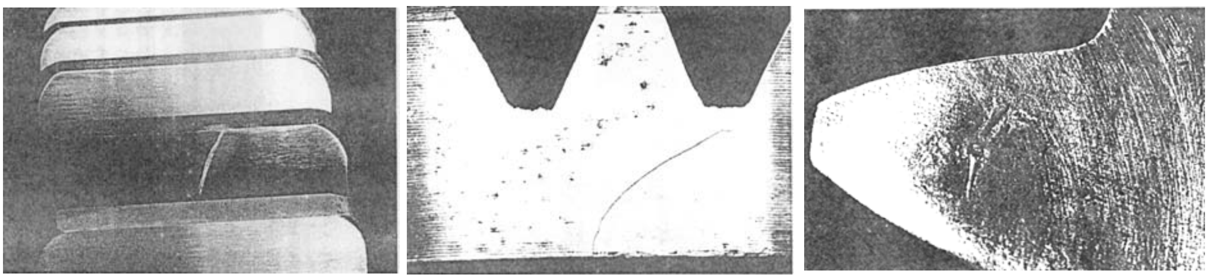
a *b* *c*



d *e*

Figure 7. Surface fatigue failures of gear teeth
(a- initial pitting ; b - progressive pitting; c - micropitting; d - flake pitting; e - spalling)

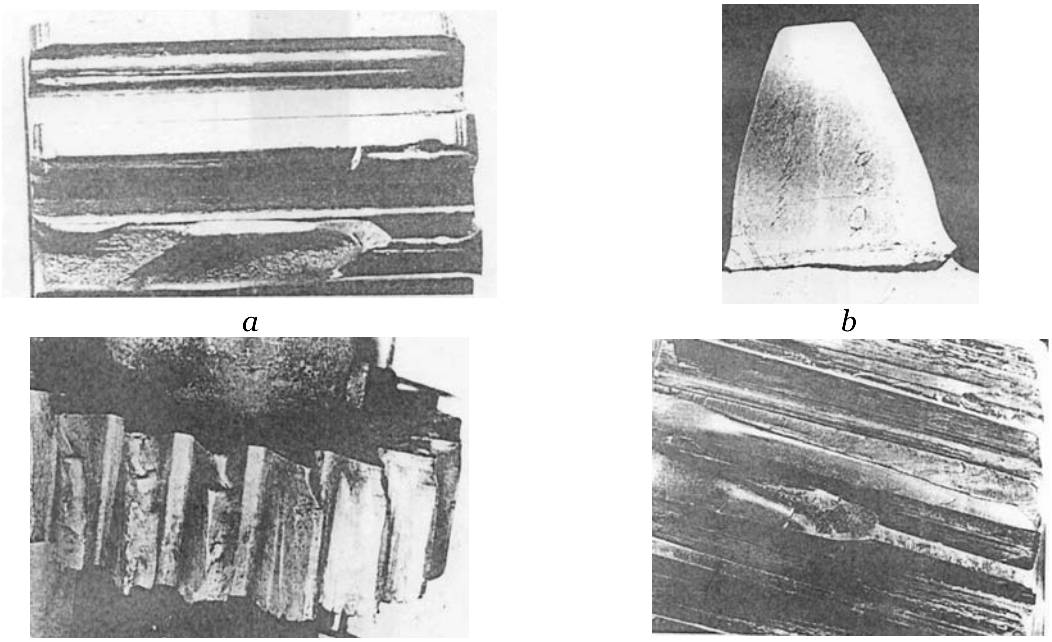
Fissures and cracks of gear (Fig. 8) can occur even before gear start to transfer torque, i.e. in its manufacturing phase. They usually occur as a result of defects, filthiness and gas inclusions in material that gear is made of, and also as a result of improper heat treatment, high internal stresses and defects during grinding operation.



a *b* *c*

Figure 8. Fissures and cracks of gear teeth
(a- crack caused by a forging defects; b – crack in the rim of a wheel due to inadequate rim thickness; c – fatigue crack which has appeared in the tooth root fillet below the loaded flank)

Tooth breakage usually occurs at the tooth dedendum, where the stresses are higher, especially on flexion tooth flank. It also may occur on the other place when it is a result of pitting process, fault heat treatment or other failures on flanks. These failures are classified as: overload breakage (Fig. 9-a), tooth shear (Fig. 9-b), breakage after plastic deformation, so called smeared fracture (Fig. 9-c) and fatigue breakage (Fig. 9-d). When overload breakage happens, several teeth are damaged, and if it is fatigue breakage, usually one tooth is damaged.



a *b* *c* *d*

Figure 9. Surface fatigue failures of gear teeth
(a- overload breakage; b - tooth shear; c - smeared fracture; d - fatigue breakage)

4. PROBLEM DESCRIPTION

After testings of new series of gear reducers of axis height 90 mm, it is identified that early failures of some components occur and that reducer rapidly degrades. These early breakdowns of reducer are caused due to constructional faults and design defects. Problem occurs because gear reducer is not adapted to projected load capacity, so that projected output torque can not be achieved, for such defined sets of gears and current reducer construction. Projected output torque value is defined according to new series of reducers of leading manufacturers of gear units. However, because of constructional faults and design defects, Sever's gear reducers are not capable to fulfill established demands. Values of gear ratii are satisfied, but still output torque is not, so that Sever's gear reducers can not be competitive on the market.

Testings are carried out on two stages and three stages gear reducers according to standard program and testing methodology of gear units that is used in Sever factory. After testing with particular torque value, gear reducer is disassembled and every component is being examined and analyzed. If total breakdown of some component occurs, or some failures are noticed, testings are being repeated with smaller torque. The biggest output torque, for which breakdowns and failures do not occur, is adopted as nominal permitted output torque for particular gear ratio.

According to defined testing methodology, testings are carried out for reducer with the smallest overall gear ratio, and at the same time the biggest gear ratio on output gear stage. For this two stages gear reducer, it is gear set with speed ratio 9.73, and for three stages variant, it is gear set with speed ratio 96. After testings of both variants of reducer, besides some failures of shaft and bearing, following failures of gears are also noticed:

% failure of output gear pair, i.e. occurring pitting and uneven loading trace on tooth flanks;
% uneven loading trace also on the first gear pair, as well as pitting occurrence on pinion of the first pair, due to excessive deformation of input shaft.

5. RESULTS AND CONCLUSION

On the basis of calculated results, following modifications of present reducer design are recommended:
% modifying of axis distance of output gear stage $a_{5/6}$ from 53 mm to 54 mm;
% increasing the diameter of fifth gear shaft under the gear z_5, raising the pinion teeth number for one, from z_5 = 11 to z_5 = 12, by maintaining approximately same partial speed ratii of output gear pair;
% increasing overhanged diameter of fifth gear shaft, from 15, and 12 mm to 17 mm;
% choosing stronger cylindrical bearing, instead of NU202 it is chosen NU203.

After increasing axis distance of output gear stage $a_{5/6}$ from 53 mm to 54 mm, position of shaft axes in reducer has been changed and the axis of input shaft comes down from 11.58 mm to 12.9 mm, relating to output shaft (Fig. 10).

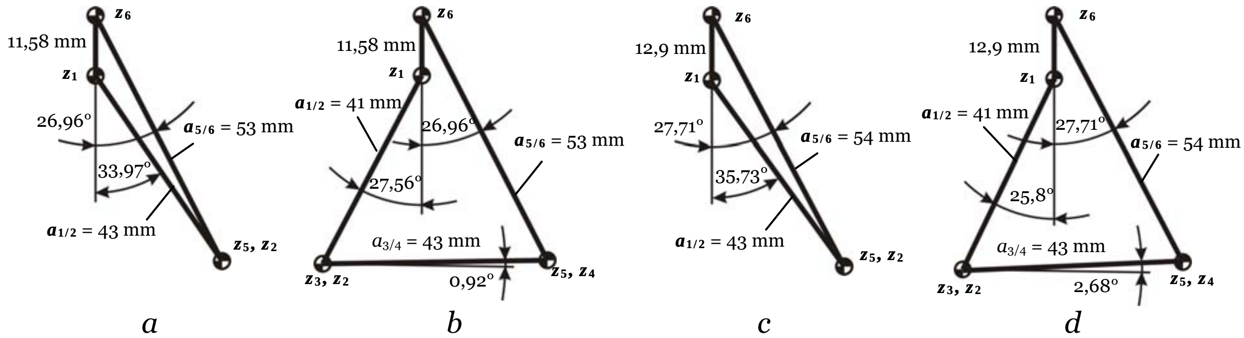


Figure 10. Position of gear axes for present design solution of gear reducer with axis height 90 mm (a - present two stages, b - present three stages) and for proposed design solution (c - proposed two stages, d - proposed three stages)

Increasing axis distance of output gear stage $a_{5/6}$ for only 1 mm enables raising teeth number of fifth gear for one, as well as teeth number of sixth gear, so that approximately same partial speed ratii will be maintained. Also, increasing teeth number of fifth gear influenced increasing rigidity and reducing shaft deformations under the gear. This simply increasing of teeth number was possible for partial speed ratii 2.94 (teeth number z_5 = 17 and z_6 = 50 has been increased to z_5 = 18 and z_6 = 53), 4.08 (teeth number z_5 = 13 and z_6 = 53 has been increased to z_5 = 14 and z_6 = 57) and for 4.91 (teeth number z_5 = 11 and z_6 = 54 has been increased to z_5 = 12 and z_6 = 59). Thus, loading capability of gear pair z_5 / z_6 enabled carrying projected output torque. However, for speed ratio 6.27 (teeth number z_5 = 11 and z_6 = 69 has been increased to z_5 = 12 and z_6 = 75), due to insufficient axis distance, loading capability was not satisfied. Because of that, teeth number of sixth gear is reduced to z_6 = 73, so that projected output torque could be satisfied, but with negligible reducing of speed ratio, i.e. from 6.25 to 6.08 (Fig. 11).

It is demonstrated that it is possible to reduce breakdown intensity and to prevent failures of gears and thus increase loading capability of two stages and three stages gear reducers by applying certain design modification and avoiding constructing faults.

This paper gives a review of different types of gear failures which can occur due to various kinds of malfunctions and unproper working condition. Gear failures usually occur due to design faults, wrong assembling and mounting, poor maintenance and uncareful manipulating.

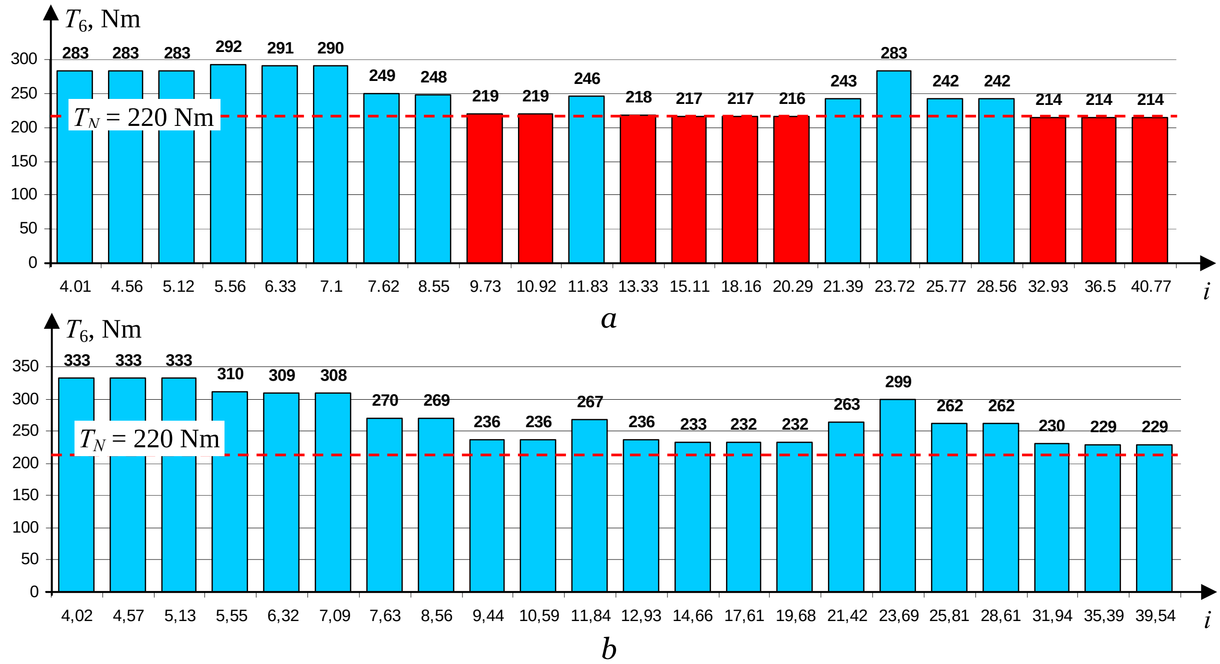


Figure 11. Permissive output torques of present (a) and proposed (b) design solution of two stages gear reducer with axis height 90 mm depending on endurance of teeth flanks of output gear pair z_5/z_6

After recommended design modifications, significant increasing of loading capacity of gear reducer is obtained. After carried out modifications, projected parameters of gear reducer are achieved, so that analyzed construction of Sever's reducer can be competitive with other leading manufacturers of gear units. Proposed modifications should be implemented to all other dimensions of gear reducers' family, which will enable successful access of these reducers to world market.

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