UDK 62-11

Prilagoditveno in variantno konstruiranje vrtljivih zvez
Variant and Adjustable Design of Rotational Connections

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0. UVOD

V strojništvu je velik del razvoja posameznih izdelkov izpeljan s prilagoditvenim ali variantnim načinom konstruiranja. V prispevku so raziskane možnosti metod konstrukcijskih postopkov, ki so vezani na način konstruiranja in uporabo računalništva na področju konstruiranja v proizvodnji vrtljivih zvez. Razvoj programskega sklopa na podlagi znanja za snovanje in konstruiranje vrtljivih zvez je pokazal, da je to uspešna in edina pot za izboljšanje kakovosti in učinkovitosti standardnih sistemov CAD.

1. NAČINI KONSTRUIRANJA

Spekter uporabe vrtljivih zvez velikih dimezij je zelo širok. Največji delež zavzamejo najrazličnejše vrste dvigal in drugih transportnih strojev in naprav, vendar je znanih tudi mnogo izpeljav v različni tehnološki opremi. Vrtljiva zveza mora z vsemi sestavnimi elementi zadostiti zahtevanim kriterijem tako glede nosilnosti kakor tudi velike natančnosti pri obratovanju. Široka namemba pa terja tudi veliko oblikovnih modelov. Predvsem so pomembne tehnološke podrobnosti, ki v pretežni meri vplivajo na nosilnost in obratovalne zmožnosti vrtljivih zvez. Oblikovni modeli pa se lahko glede na namen le malo razlikujejo.

Konstrukcijski proces je običajno dodatno podprt z ustreznim načinom oblikovanja in uporabo računalniške tehnologije. S tem razvoj izdelka sledi cilju, tj. omejeni čas, manjši stroški in boljša kakovost. Izdelovalcu posameznega izdelka se pri tem zastavi vprašanje, katere metode konstruiranja in kateri pripomočki so primerni in so v konstrukcijski praksi učinkovito uporabni. Pravilna odločitev o izbiri konstrukcijskega postopka je mogoča samo tedaj, če so poprej analizirana vsebinska vprašanja posameznih stopenj razvoja: načrtovanje, zasnova, osnutek in izdelava (sl. 1) — in znani ter definirani posamezni načini konstruiranja.

Iz literature [1] so znane naslednje definicije za posamezne načine konstruiranja:

— konstruiranje na novo: sprejeto je povsem novo načelo rešitve pri enakem, spremenjenem ali

0. INTRODUCTION

In mechanical engineering, a great many products are designed by applying variational or adjustment principles. This article describes the possibilities of designing procedural methods related to the use of computers in the field of rotational connections design and production. The development of a knowledge-based program complex for rotational connection design has proven to be the only successful way of providing high quality and efficiency augmentation of conventional CAD systems.

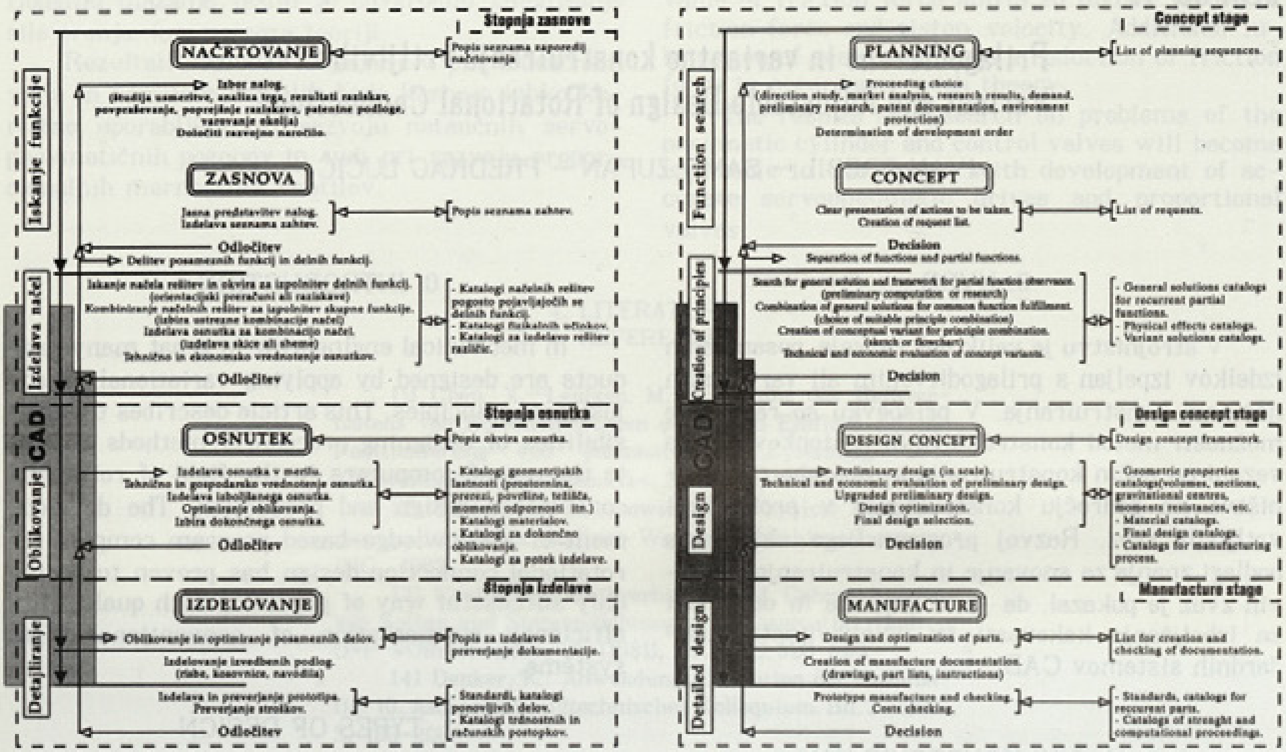
1. TYPES OF DESIGN

Large diameter rotational connections have a very broad scope of use. The major share is taken by various kinds of cranes and other lifting and conveying machinery, although many applications in industrial processing equipment are known as well. A rotational connection, with all its elements, has to satisfy the required criteria of load carrying capacity and running accuracy. Further, the broad scope of use requires a large number of different models. The greatest importance is attached to technological details that greatly affect the load carrying and operational capabilities of rotational connections. The models, though, may differ only slightly with respect to their intended use.

The design process is usually additionally supported by an appropriate design procedure and the application of computer technology. Such support is required to achieve the primary goals: short times, lower costs and higher quality. It is up to the manufacturer of a particular product to decide which design procedures and aids are suitable and efficiently usable in practice. The right decision on the selection of a design procedure can be reached only after a detailed analysis of every single development stage - planning, preliminary design, outline, manufacture (Fig. 1) - and an exact definition of design procedures.

The literature [1] gives the following definitions of different design procedures:

— Novel design: a completely new principle of solution has been devised while the basic



Sl. 1. *Potek razvoja izdelka po priporočilu VDI 222.*

Fig. 1. *Complete design process of a product according to VDI 222 recommendations.*

na novo postavljenem sistemu (naprava, stroj, ali skupina sklopov ali podsklopov);

— prilagoditveno konstruiranje: prilagojen je znan sistem (načelo rešitve je znano in ostane nespremenjeno) glede na nove zahteve, pri tem je treba v večini primerov posamezne sestavne elemente ali podsklope konstruirati na novo;

— variantno konstruiranje: variante so posamezne veličine ali razporeditve v mejah vnaprej postavljenega sistema, funkcija in načelo rešitve ostaneta nespremenjena, znani pa so tudi parametri materiala, tehnologije in obremenitev.

Če izhajamo iz teh definicij, potem v splošnem velja v strojni industriji, da pretežni del, to je 70 odstotkov konstrukterskega dela (analize velikih podjetij) [1], odpade na prilagoditveno in variantno konstruiranje in le manjši del na konstruiranje na novo.

1.1 Postavitev metod konstrukterskih postopkov

Izkušnje in statistične analize [2] kažejo, da se, neodvisno od načina konstruiranja, metode oblikovanja v industrijski praksi uporabljajo vedno manj, kar velja še posebno za manjša podjetja. To nazadovanje konstrukterji opravičujemo z neprilagodlji-

system (instrument, machine, a group of structures or substructures) can be the same, slightly changed, or completely new.

— Adaptive design: a known system is adapted to satisfy new demands (the principle of solution is known and remains unchanged). In most cases it is necessary to design the individual components and substructures anew.

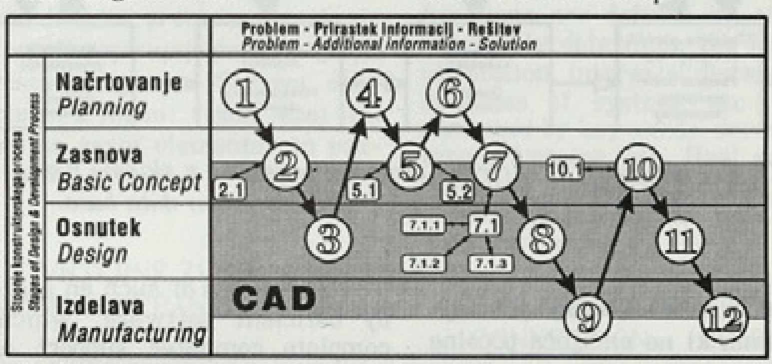
— Variant design: some magnitudes or layouts are varied in the limits of a predetermined system. The function and the principle of solution remain unchanged, and the parameters of material, loads and technology are known.

Based on the above definitions, it can be stated, according to analyses in big companies, that approx. 70% of design work consists of adaptive and variant design, and only a minor part can be characterized as novel design.

1.1 Methods in Design Procedures

Experience and statistical analyses [2] show that the use of design methods in industry is declining, regardless of the method of design. This is true especially for smaller enterprises. The designers justify this decline by lack of flexibility, abstractness and excessive formalism of methods vostjo, abstraktnostjo in formalizmom metod in analitičnih postopkov, ki so bili razviti v sedemdesetih letih, kar še posebej velja za nemško vplivno področje. Metode dejansko vsiljujejo, naj poteka konstrukterski proces od stopnje do stopnje v linearnem zaporedju, od zastavljenih nalog pa do izdelave dokumentacije, čeprav avtorji teh metod vedno znova opozarjajo na nujnost iterativnosti postokov. Izkušnje potrjujejo to obrazložitev. Glede na zapletenost konstrukterskih nalog, sestavo konstrukterske skupine in razpoložljivega časa konstruiranja so metode splošno znanih stopenj konstruiranja: načrtovanje, snovanje, oblikovanje in izdelava razporejene običajno tako, da zadostijo potrebam dopolnjevanja in stopnjevanja konstrukterskega procesa. To velja za vse načine konstruiranja, posebej pa še za prilagoditveno in variantno ter zamisli in rešitve z majhno konstrukcijsko svobodo. Raziskave [3] kažejo, da so stopnje konstrukterskega procesa povezane z značilnostjo delovnih korakov in ne sledijo druga drugi deterministično, ampak se lahko po potrebi spremenijo. Delovni koraki potekajo pri tem v obliki cikla. Vsak delovni cikel pa se sme gledati kot krog pravil poudarjenih korakov, tj. oblikovanje, izvajanje in vrednotenje delovnega koraka.

and analytical procedures which were developed in the seventies. These peculiarities are especially apparent in the German influenced regions. The methods actually suggest that designing should proceed step by step in a linear fashion, from design specifications to creation of documentation, although the authors have repeatedly pointed out the necessity of iterative use of procedures. Experience confirms this. The methods of the well known design steps (planning, drafting, actual design, manufacturing) are usually set up so as to fulfill the requirements of supplementing and intensifying the design process, taking into account the complexity of the required design, the composition of design team and the time available. This applies to all methods of design, especially to adaptive and variant design as well as to concepts and solutions with little freedom of design. Research [3] shows how the steps of design process are linked by the work step characteristic. They do not follow one another in a deterministic way, but can be changed if required. Work steps take the form of a cycle. Each work cycle can be regarded as a circle of rules of emphasized steps, that is - formulation, execution and evaluation of a work step.



Sl. 2. *Prikaz delovnega procesa kot iterativna povezava delovnih korakov.*
Fig. 2. *Work process as iterative linkage of work steps.*

Slika 2 prikazuje potek delovnih korakov, ki lahko potekajo v določenem konstrukcijskem procesu. Pri tem je jasno, da so konstrukterske stopnje: načrtovanje, zasnova, osnutek in izdelava obravnavane le kot členi konstrukterskega procesa in nič več kot posledica delovnih korakov. Delovne korake spreminjamo skokoma med posameznimi konstrukcijskimi stopnjami. Konstrukterski proces pa se tako z iterativnim povezovanjem delovnih korakov postopoma razjasni.

Za računalniško podprto konstruiranje je primerna uporaba modulnih struktur, ki se dobro izkažejo pri modulni gradnji. Za modulno sestavljene delovne korake je priporočena uporaba podsistemov, kar še posebej velja pri variantnem in prilagodljivem konstruiranju, pri katerih običajno potekajo le delne konstrukcijske stopnje.

Fig. 2 shows the flow chart of work steps that can be executed in an actual design process. It is clear that individual design stages — planning, drafting of the initial design, and manufacture — are assessed merely as links in a design process and not, as before, as a result of work steps. Work steps change by leaps among individual design steps. The design process can thus be clarified gradually by way of iterative linking of work steps.

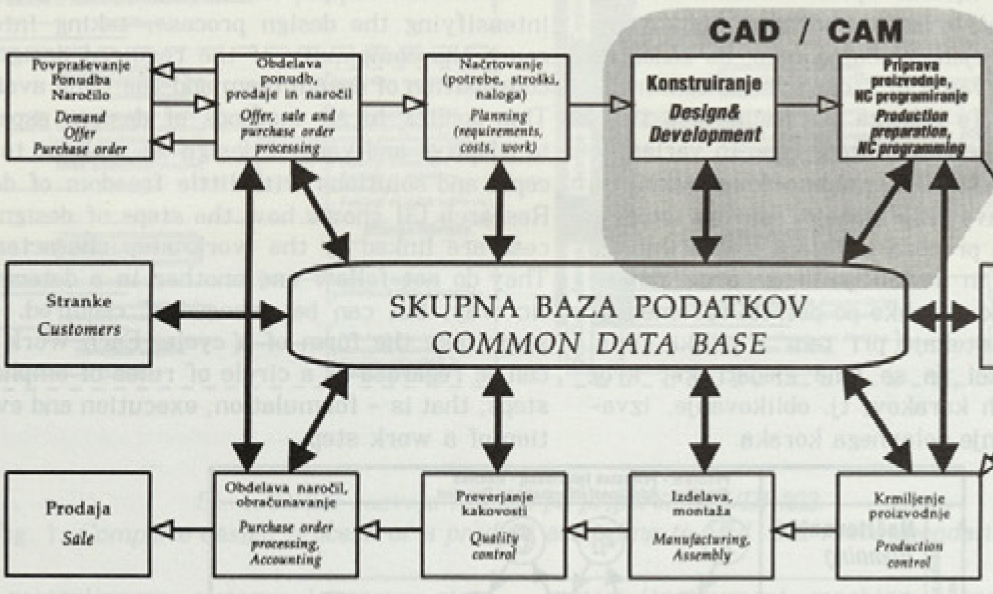
In Computer Aided Designing it is reasonable to use modular structures, which demonstrate their advantages in module oriented product designs. The use of subsystems is recommended for the modular setup of work steps, especially with adaptive and variant designs, where usually only partial design steps are carried out.

1.2 Računalniška podpora procesa konstruiranja — podatkovna baza

Če se proces konstruiranja razume kot obdelava informacij, potem lahko te informacije logično preuredimo in postopoma računalniško obdelamo. Izkušnje kažejo, da je treba celoten razvojni in proizvodni proces razdeliti na posamezne odseke in jih šele nato računalniško obdelati kot delne procese (sl. 3).

1.2 Computer Support of the Design Process—Data Base

If the design process can be interpreted as information processing, then this information can be logically arranged and gradually computer-processed. Past experience has shown that the entire development and production process should be separated into segments, and these segments then processed by a computer as partial processes (Fig. 3).



Sl. 3. *Predstavitev integrirane obdelave podatkov s skupno bazo.*
Fig. 3. *Integrated data processing with common data base.*

Vzrok za takšen način razmišljanja je pomanjkljiva programska oprema, ki ne omogoča popolne podpore računalništva in njegove povezave s konstrukcijskimi metodami in postopki. Le 40 odstotkov dejavnosti, ki je v konstrukterskem procesu računalniško podprta, odpade na stopnji zasnove in oblikovanja. Preostali del je vezan na izdelavo dokumentacije. Podatki o izdelku so med seboj povezani z določenimi razmerji in so med seboj odvisni. V konstrukcijskem procesu vrtljivih zvez se obseg podatkov od stopnje do stopnje razvojnega procesa zelo povečuje. Podatki, ki v popolnosti popišejo izdelek skozi vse njegove razvojne stopnje, so običajno razdeljeni v štiri glavne skupine:

— geometrijski podatki o makro in mikro geometrijski obliki, popišejo tudi dimenzije (modela, tolerance, ujeme itn.);

— tehnološki podatki o materialu, postopkih obdelave, obdelovalnih centrih, itn:

— funkcionalni podatki o vzdrževanju in delovanju izdelka (rezultati vrednotenja, funkcijske strukture, navodila za uporabo itn.);

The choice of such an approach is conditioned by deficient software, which does not allow complete computer support and its connection with design methods and procedures. Planning and actual designing amount to only 40% of computer supported activities in the design process, while the rest is associated with creation of documentation. The product data are interconnected by certain relations, and are interdependent. The amount of data in the design process increases dramatically from one development step to another. The data describing the product in full throughout its development phases can be divided into four main groups:

— geometric data, providing macro- and micro-geometry, shape and general dimensions (of a model, tolerances, fits etc.);

— technological data, providing characteristics of material, machining procedures, machining centres etc.

— functional data, covering product maintenance and operation data and instructions (evaluation results, functional structures, instructions for use, etc.);

— organizacijski podatki razpoznavajo izdelek (protokol pregleda, klasifikacijo ponovne uporabe, pripadnost elementa itn.).

Funkcije, pripadajoča delovna načela, oblikovni modeli in funkcijske povezave so popisane zelo natančno in so tako organizirane, da je za izbrane delovne funkcije mogoč izbor vseh znanih stvarnih oblikovnih modelov, načelnih in že znanih rešitev, predpisov, standardov, priporočil, materialov, tehnoloških parametrov, poteka montaže itn.

Omogočeno je preprosto dopolnjevanje podatkovne baze in znanja z novimi rezultati raziskav in dosežki s področja vrtljivih zvez, ležajev velikih dimenzij, dinamično obremenjenih vijačnih zvez, valjastih zobniških dvojic itn. Zapis znanja je strukturiran, znanje je podano z zbirko dejstev in s splošnimi postopki za delovanje, sklepanje pa se lahko izpelje z enotnimi mehanizmi. Prednosti strukturiranega zapisa znanja so v tem, da je vsak podatek predstavljen le enkrat, da je mogoče dodajati nove ne da bi bilo treba spreminjati že zapisano lastnost ali proces za opravilo z njimi [4], [5]. Osnovne in povezovalne funkcije so predpisane z algoritmi za popis fizikalnih funkcij, prostorskih razmerij, prenosa energije itn. Dopolnilne funkcije natančneje določajo osnovno funkcijo: smer vrtenja, medosni razmik, kotalni premer, togost sistema itn. Delovna načela popisujejo pojmi: vijačna zveza, tesnjenje, vrsta ozobja itn. Stvarni oblikovni modeli so popisani z imeni: vijak, ležaj itn. in so definirani samo na ravni elementov in podsklopov.

2. SNOVANJE VRTLJIVE ZVEZE — (MEHANIZEM SKLEPANJA)

Uporabnik določi izhodiščno stanje — funkcijo, ki naj jo dejansko zveza opravlja [5]. Vse osnovne in dodatne funkcije, ki jih sistem podpira, so navedene v bazi funkcij, ki je dostopna prek posebnega ukaza. Po tej fazi se začne sklepanje oziroma iskanje produkcijskega pravila, katerega funkcija ustreza izhodiščnemu stanju.

V trenutku, ko je rešitev znana, se pokažejo vsa delovna načela, ki izpolnjujejo izhodiščno funkcijo. Na tem mestu se lahko postavi zahteva po dodatnem vprašanju: uporabniku je omogočen vnos dopolnilne funkcije. Sistem preveri dopolnilne funkcije le tistih delovnih načel, ki že izpolnjujejo osnovno funkcijo. Uporabnik se na podlagi tega odloči za tiste sestavne elemente in pripadajoče oblikovne modele, za katere želi, da so uporabljeni v vrtljivi zvezi. Proces sklepanja se nadaljuje na ponavljajoč način do vzpostavitve dejanskega tehničnega sistema, ki izpolnjuje na samem začetku podano funkcijo. Pri tem izhajamo iz uporabniških

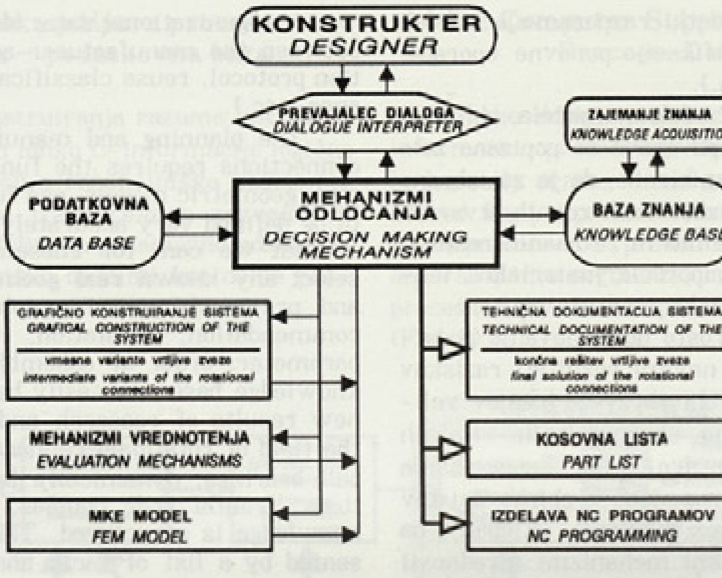
— organizational data, identifying the product between the manufacturer and the user (inspection protocol, reuse classification, element adherence, etc.).

The planning and manufacture of rotational connections requires the functions, work principles, geometric models, and functional connections to be defined very accurately. They are organized so that we can, for chosen working functions, select any known real geometric model, general and previously existing solution, standard, recommendation, regulation, material, technologic parameter, order of assembly etc. The data and knowledge base can easily be supplemented with new results of research and achievements from the field of rotational connections, large diameter ball bearings, dynamically loaded screw connections, frontal gear couples, etc. The record of knowledge is structured. The knowledge is presented by a list of facts and general procedures for manipulation, and conclusions can be reached by applying uniform mechanisms. The advantages of a structured record of knowledge are that every fact is presented only once, and it is possible to add new facts without changing or rearranging the existing ones or their manipulation procedures [4], [5]. The basic and linking functions are defined by algorithms for physical functions, space ratios, energy transfer, etc. Auxiliary functions are defined by the facts which more accurately determine the basic function — sense of rotation, interaxial distance, raceway diameter, stiffness of system, etc. Work principles are described by keywords: screw connection, sealing, type of gearing, etc. Real geometrical models are described by names: screw, bearing, etc., and are defined only on the level of components and substructures.

2. PLANNING (DRAFT) OF ROTATIONAL CONNECTION - (CONCLUSION MAKING MECHANISM)

The user defines the initial conditions — the required function of rotational connection [5]. All the basic and additional functions supported by the system are stored in the function base, accessible via a reserved command. After this stage the conclusion making process begins, the search for the production rule, the function of which corresponds to the initial conditions.

The moment the solution is found, all the work principles fulfilling the initial conditions become evident. At this point, an additional question can be set - the user is able to enter a supplementary function. The system checks supplementary functions of only those work principles which already fulfill the basic function. On the basis of the available information, the user selects the component parts to be used in the rotational connection. The conclusion making process continues repeatedly until a real technical system fulfilling the initially defined function is



Sl. 4. *Zgradba in informacijski tok v konstrukterskem programskem sistemu, temelječem na bazi znanja (SBZ).*

Fig. 4. *Set-up and information flow in a knowledge-based design software.*

zahtev, ki popišejo zunanje obremenitve zveze, vir in prenos energije, način vpetja, vrsto objekta in iz tega izhajajočo varnost, okolje in klimatske razmere, način montaže, nadzora itn. [5]. Bistveno je obremenitveno stanje, po katerem se v danih razmerah vgradnje po dopolnjenih [5], [6], [7] metodah dimenzioniranja kotalnih ležajev, zobniških dvojic in vijačnih zvez, izoblikuje oblikovni model ležaja velikih dimenzij kot osnovnega dela vrtljive zveze (sl. 5).

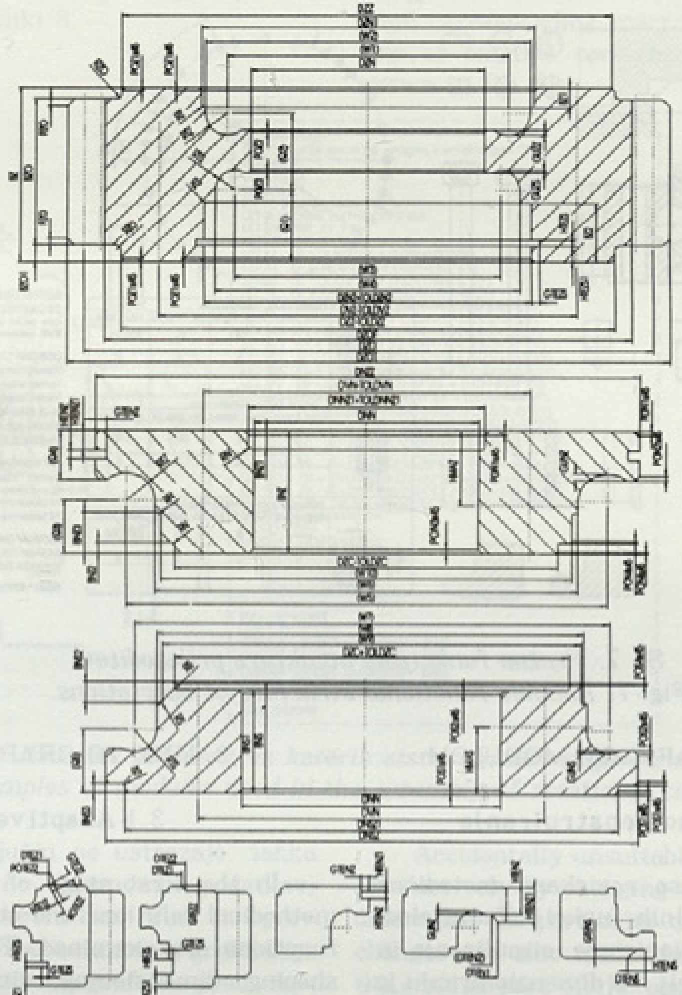
Izbira mehanizma sklepanja poteka z uporabo modula za dialog (sl. 4). Mehanizmi sklepanja pomenijo izbor metod dimenzioniranja in kriterije omejitev. Narava konstrukcijskega procesa je taka, da vrstni red posameznih operacij ni vedno predpisan. To zahteva prepletenost programskih podsklopov oziroma baz. Rezultati posameznih postopkov dimenzioniranja morajo biti očitni in na voljo pri drugih preračunih, na primer: možni razdelni premer zobnika na ležaju je odvisen tudi od kotalnega premera ležaja, razdelnega kroga vijačne zveze, premera vijakov itn. Rezultati se lahko pojavljajo kot vhodni podatki v preostalih podsestavih. Omogočajo zamenjavo podatkov ali pa dopoljujejo posamezne baze z novimi podatki. Pretok podatkov je omogočen v smeri modula za dimenzioniranje in izdelavo dokumentacije in nasprotno. To je še posebej pomembno pri optimiranju posameznih geometrijskih modelov (sl. 5), ki se z analizo funkcionalnosti določijo v vseh nadrobnostih [5]. Tako je tehnični model podan z geometrijsko obliko, tolerancami in podatki o funkcionalnosti.

achieved. The assumptions take into account exploitation requests describing the external loads of the connection, energy source and transfer, kind of fixing, type of basic object and resulting safety, environmental, and climatic conditions, method of assembly, inspection, etc.[5]. Vitally important are the load conditions on the basis of which - with given installation conditions according to the modified [5], [6], [7] dimensioning methods for roller bearings, gear pairs and screw connections - the geometric model (Fig. 5) of a large diameter ball bearing is formed, representing the main part of a rotational connection.

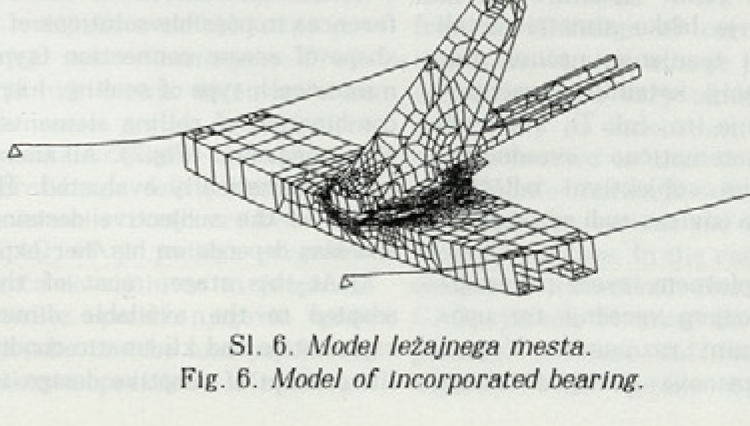
The conclusion making mechanism is chosen by way of a dialogue module (Fig. 4). These mechanisms consist of a selection of dimensioning methods and limiting criteria. The nature of the design process is such that the order of separate operations is not always determined, which in turn requires complex intertwining of data bases and subsets. The results of every single dimensioning procedure must be transparent and available to other computation procedures, e.g.: possible gear pitch circle depends on bearing raceway diameter, screw connection pitch, screw diameter, etc. The results can be used as input to other substructures of the program. They can be changed or they complement individual data bases with new data. Data flow is possible in both directions, to and from the dimensioning and documentation creation module. This is particularly important in optimizing individual geometric models (Fig. 5) that are defined in detail by the analysis of functionality [5]. The technical model is thus defined by geometry, tolerances and data on functionality.

Na dobo trajanja vrtljive zveze ob znanih parametrih [5] vpliva tudi porazdelitev obremenitve pri posameznih kotalnih elementih. Pri tem je neenakomernost porazdelitve obremenitve odvisna od razmerja togosti nasproti ležečih podpornih konstrukcij. Zato je za zahtevne sisteme treba preveriti deformacijsko stanje nosilne konstrukcije (sl. 6) in ležaja pri različnih primerih obremenitve .

The lifetime of a rotational connection of known parameters [5] is also affected by the distribution of loads on separate rolling elements. Here the non-uniformity of the distribution depends on the stiffness ratio of oppositely supporting parts. With complicated systems, it is therefore necessary to check the deformations of the supporting structure (Fig.6) and bearings at different loads.



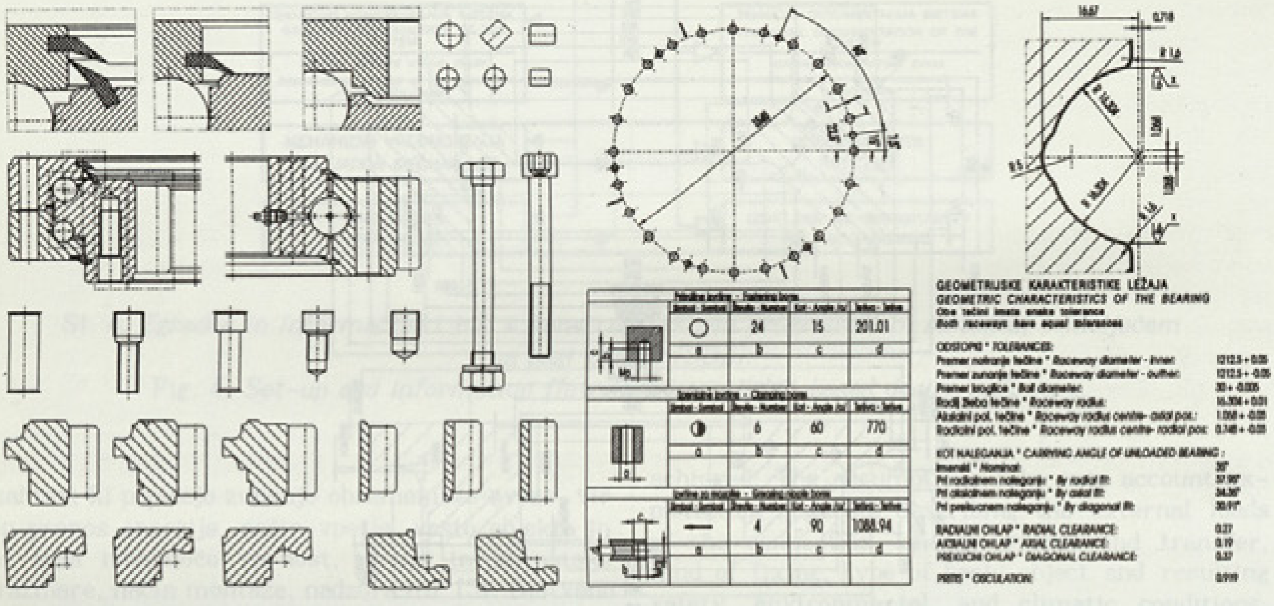
Sl. 5. *Primer popisa tehničnega modela.*
Fig. 5. *Example of technical model description.*



Sl. 6. *Model ležajnega mesta.*
Fig. 6. *Model of incorporated bearing.*

Prenos in uporaba določenih dvodimenzionalnih geometrijskih podatkov olajša in pospeši izdelavo tridimenzionalnega modela s postopkom končnih elementov (FEM), ki je primerna metoda za preverjanje podpornih konstrukcij. Rezultati vrednotenja pa so podlaga za izbiro parametrov in oblikovanje tečine ležaja: ohlapnost, pritis, imenski kot nošenja itn. (sl. 7).

The transfer and use of certain two-dimensional and three-dimensional geometric data simplifies and speeds up the creation of a FEM model, which is a suitable method of supporting structure checks. The results of the evaluation are the basis for the choice of raceway parameters: play, pressing, nominal carrying angle, etc. (Fig. 7).



Sl. 7. *Prožna funkcijska struktura prilagoditev.*
Fig. 7. *Flexible functional structure of adaptations.*

3. POVEZAVA Z GRAFIČNIM MODULOM

3.1 **Prilagoditveno konstruiranje**

V prvi stopnji razvoja so raziskane metodične rešitve in kombinacije delnih funkcij. Temu sledi grobo oblikovanje, dimenzioniranje, simuliranje in preverjanje nosilnih funkcij. Po dimenzioniranju je oblika vrtljive zveze določena v grobem, tj. določene so mogoče velikosti najpomembnejših dimenzij. Zaradi raznovrstne uporabe vrtljivih zvez se pojavljajo pomembne razlike pri možnih rešitvah še pri načinu pritrditve, obliki vijačne zveze in razporeditvi vijakov, ki je lahko simetrična ali tudi nesimetrična, obliki tesnjenja, načinu mazanja, obliki in kombinaciji kotalnih elementov, vrstah in oblikah ozobljenja itn. (sl. 7). Vseh teh rešitev ni mogoče matematično ovrednotiti. Končna izbira temelji na subjektivni odločitvi konstrukterja in je seveda odvisna tudi od njegovih izkušenj.

Na tej stopnji se v splošnem izvede prilagoditev razpoložljivim dimenzijam vgradnje ter uporabnostim in kinematičnim razmeram. V tem primeru je prevzem zasnova prilagoditvenega

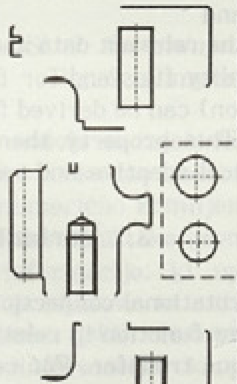
3. LINK TO GRAPHIC MODULE

3.1 **Adaptive Design**

In the first stage of the development, the methodical solutions and combinations for partial functions are examined. The next step is rough shaping, dimensioning, simulation and carrying function checking. After dimensioning, the shape of a rotational connection is roughly defined, i.e. the possible magnitudes of the most important dimensions are specified. Because of the wide use of rotational connections there are important differences in possible solutions of the kind of fixing, shape of screw connection (symmetrical or asymmetrical), type of sealing, lubrication, shape and combination of rolling elements, types and shape of gearing, etc. (Fig.7). All these solutions cannot be mathematically evaluated. The final choice is based on the subjective decision of the designer and also depends on his/her experience.

At this stage, most of the dimensions are adapted to the available dimensions of fixing, exploitation and kinematic conditions. In this case the concept of adaptive design is actually an imkonstruiranja bistven korak v razvoju. To omogoča grafični del programskega sklopa, ki temelji na makro sintaksi paketa CAD in je povezan s konstrukcijskim delom sistema prek krmilnega modula. V njem se prek zaslonskih izborov identificira koda ležaja iz podatkovne baze. Programski paket avtomatsko sestavi posamezne elemente ali sestav vrtljive zveze iz ustreznih makro modulov. Nekateri primeri, ki jih zajamejo taki moduli so prikazani na sliki 8.

portant step in development. This is provided by the graphic part of the software package, which is based on the macro-syntax of CAD package, and communicates with the design part via the control module. In this part, by way of screen menus, the identification code of the bearing is chosen from the data base, by means of which the program package automatically assembles separate components or a rotational connection structure from corresponding macro modules. Some examples of entities contained in such modules are shown in fig. 8.



```
DEFINE krogi
(***** risanje sp. in zg. kroglic s sredničami *****)
LOCAL T1
LOCAL EX
LOCAL EY
(***** izračun točk *****)
LET T1 (KOSBE + (PNT_XY 0 0))
LET EX (PNT_XY 1 0)
LET EY (PNT_XY 0 1)
LET T1   (T1 - DLS/2*EX + (H2N+HS)*EY)
LET T2   (T1 + DLS/2*EX + (H2N+HS)*EY)
LET T3   (T1 - DL2/2*EX + (H2N+HS+H)*EY)
LET T4   (T1 + DL2/2*EX + (H2N+HS+H)*EY)
LET ST1  (T1 - DLS/2*EX + (H2N+HS-DKS/2-3)*EY)
LET ST2  (T1 + DLS/2*EX + (H2N+HS-DKS/2-3)*EY)
LET ST3  (T1 - DLS/2*EX + (H2N+HS+DKS/2+3)*EY)
LET ST4  (T1 + DLS/2*EX + (H2N+HS+DKS/2+3)*EY)
LET ST5  (T1 - (DLS/2+DKS/2+3)*EX + (H2N+HS)*EY)
LET ST6  (T1 + (DLS/2+DKS/2+3)*EX + (H2N+HS)*EY)
LET ST7  (T1 - (DLS/2-DKS/2-3)*EX + (H2N+HS)*EY)
LET ST8  (T1 + (DLS/2-DKS/2-3)*EX + (H2N+HS)*EY)
LET ST9  (T1 - DL2/2*EX + (H2N+HS+H-DK2/2-3)*EY)
LET ST10 (T1 + DL2/2*EX + (H2N+HS+H-DK2/2-3)*EY)
LET ST11 (T1 - DL2/2*EX + (H2N+HS+H+DK2/2+3)*EY)
LET ST12 (T1 + DL2/2*EX + (H2N+HS+H+DK2/2+3)*EY)
LET ST13 (T1 - (DL2/2+DK2/2+3)*EX + (H2N+HS+H)*EY)
LET ST14 (T1 + (DL2/2+DK2/2+3)*EX + (H2N+HS+H)*EY)
LET ST15 (T1 - (DL2/2-DK2/2-3)*EX + (H2N+HS+H)*EY)
LET ST16 (T1 + (DL2/2-DK2/2-3)*EX + (H2N+HS+H)*EY)
(***** risanje srednjice *****)
COLOR RED
LINETYPE DOT_CENTER
LINE ST1 ST3 ST5 ST7
    ST2 ST4 ST6 ST8
    ST9 ST11 ST13 ST15
    ST10 ST12 ST14 ST16
(*****risanje kroglic *****)
COLOR WHITE
LINETYPE SOLID
CIRCLE CENTER T1 (DKS/2)   END
CIRCLE CENTER T2 (DKS/2)   END
CIRCLE CENTER T3 (DK2/2)   END
CIRCLE CENTER T4 (DK2/2)   END
END
END_DEFINE
```

Sl. 8. *Primeri modulov, iz katerih sistem gradi vrtljive zveze.*
Fig. 8. *Examples of modules used in the assembly of rotational connections.*

Detajle, ki po naključju ne ustrezajo, lahko prilagodimo z interaktivno spremembo podatkov, ki detajl določajo v podatkovni bazi. Tudi te spremembe se opravijo prek izborov znotraj grafičnega programskega sklopa z uporabo grafično predstavljenih navodil. Izkušen konstrukter lahko to naredi s črkovno številčnim vnosom že v stopnji snovanja še preden se oblikuje prva različica ležaja. Tak način sicer nekoliko omejuje svobodo konstruiranja različnih oblik, vendar izkušnje kažejo, da je velik odstotek vrtljivih zvez oblikovno podobnih in se razlikujejo samo dimenzijsko. Prednost takšne metode je tudi v tem, da omogoča na preprost in zanesljiv način pretok informacij v obeh smereh med konstrukcijskim sistemom na temelju znanja in grafičnega dela programskega sklopa. V primeru enkratnih izvedb vrtljivih zvez komercialni paket CAD, ki je podlaga programskemu sklopu, omogoča dovolj hitro in preprosto prilagoditev detajla tudi z uporabo njegovih vgrajenih funkcij. Seveda take izvedbe niso popolnoma definirane v bazi skupin podatkov. Medsebojna

Accidentally unsuitable details can be changed interactively by changing the relevant data which determine the particular detail in the base. These changes are also made through selections within the graphic part of the package by way of graphically presented instructions. An experienced designer can make them by way of an alphanumeric entry even in an earlier stage, before the first version of the bearing is constructed. The fact is that this kind of work somewhat limits the freedom of design of certain shapes, but experience shows that a large percentage of rotational connections are very similar in shape, and they differ only in dimensions. Another advantage of such a method is that it provides a simple and reliable information flow between the knowledge-based design system and the graphic part of the program package. In the case of completely unique designs of rotational connections, a commercial CAD system, forming the basis of the program package, provides sufficiently fast and simple adjustment of details by using its built-in povezava posameznih elementov (modelov) v sklopu je v grafičnem programskem paketu vodena prek kosovnice, ki pomeni dejanski sistem vodenja. Tako nastane sklenjen model z naslednjimi prednostmi:

— popolnoma razpoložljive lastnosti vrtljive zveze (funkcija, oblika, tehnologija) so med seboj povezane;

— prepreči se zamenjava datotek s sorodno vsebino;

— popolna prehodnost vseh podatkov skozi stopnje konstrukcijskega procesa od zahtev do kompletne dokumentacije;

— iz popolnega modela izdelka se lahko izpelje potrebne podatke in podlage za ohranjanje kakovostnih datotek in nadaljnjo uporabo (NC, dokumentacija). To omogoča uspešno in preudarno prilagoditveno in variantno konstruiranje.

3.2 Variantno konstruiranje

Ležaji prevzemajo pri vrtljivi zvezi pomembno funkcijo tako pri nosilnosti kakor tudi pri prenosu vrtilnega momenta. Za določene uporabne razmere definiramo dokončen geometrijski model, pri katerem ostaneta funkcija in načelo rešitve v pretežni meri nespremenjena. Spreminjajo se le posamezne veličine ali razporeditve vnaprej postavljenih robnih pogojev. Variantno konstruiranje posameznih delov ali sklopa se zato odvija po natančno določenih konstrukcijskih pravilih (oblikovni modeli, kriteriji, potek izdelave itn.) in klasifikacijskem sistemu, ki omogoča ponovno uporabo. V ta namen so pripravljeni podatki o razvejanosti in kosovna lista za strukturiranje celotnega sklopa oziroma samo elementov. To pomeni, da je dokumentacija konstrukcije ležaja več kakor samo spreminjanje geometrijskega modela posameznih elementov. To je pravzaprav spreminjanje celotnega sestava pod pogoji, ki jih definirajo konstrukcijska pravila in klasifikacijski sistem. Variantno konstruiranje je tako definirano po naslednjih stopnjah:

— za posamezne elemente ali sestav z enako topologijo in spreminjajočo se geometrijsko obliko,

— za posamezne elemente ali sestav z spreminjanjem topologije in geometrijske oblike po pravilih konstruiranja.

Vrtljiva zveza je običajno sestavljena iz posameznih elementov: zunanji (zunanja) in notranji (notranja) obroč(a), vijaki, kotalni elementi, distančniki, mazalni sistem, čep in zatič. Najprej vedno poizkušamo po pravilih konstruiranja in klasifikacije poiskati vrtljivo zvezo s ponovno uporabo in šele nato pristopimo s programom za generiranje k spreminjanju geometrijskega modela

functions. Certainly, such solutions are not fully defined in the data and macrobases. The interconnection of separate components (models) in a substructure is made in the graphic part of the package via the parts list, which is the actual control system. Thus the complete system is created, with the following advantages:

— fully available properties of the product (function, shape, technology) are relationally interconnected,

— mistaking files with similar contents is practically impossible,

— complete transitivity and accessability of data through all stages of the design process from the initial requirements to complete documentation, and

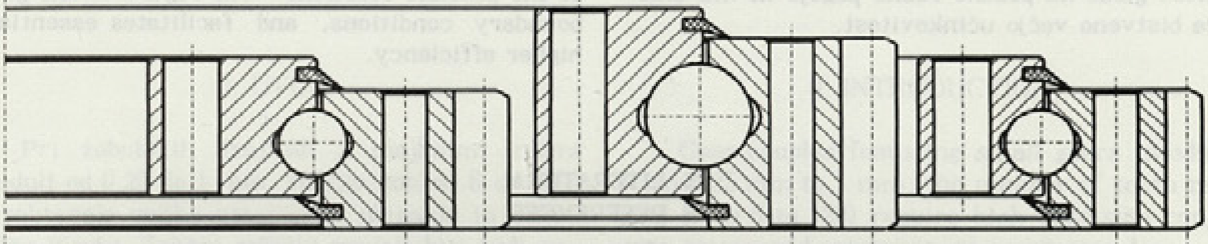
— the relevant data and bases for maintaining good quality files and for further use (NC, documentation) can be derived from a complete product model. This property then enables efficient and economical adaptive and variant design.

3.2 Variant Design

In rotational connections, the bearings have an important function in relation to carrying capacity and torque transfer. For certain exploitation conditions, a final geometric model is defined, the function and solution principles of which remain to a large extent unchanged. Only separate dimensions or layouts according to the pre-set boundary conditions are varied. Variant design of individual components or substructures, therefore, follows precisely determined design rules (geometric models, criteria, manufacturing procedure, etc.) and a classification system supporting the reuse conditions. For this purpose, data on tree structure and parts list for the structuring of substructures, or merely components, are prepared. The documentation of bearing design is, in this case, more than just a variation of the geometric model of separate elements. As a matter of fact, this represents a variation of the complete structure under conditions defined by design rules and classification system. Variant design can thus be defined by the following steps: - variant design for individual components or a substructure with fixed topology and varied geometry, and - variant design for individual components or a substructure with variations of topology and geometry on the basis of design rules.

A rotational connection consists of separate components: outer and inner ring, screws, rolling elements, distance rings, lubrication system, plug and pin. First, we always try to find a reusable rotational connection taking into account the design rules and classification. Next comes the za želene pogoje, pri čemer je na voljo tudi seznam standardnih delov (kotalni elementi, mazalni sistem, distančniki, zatiči itn.) (sl. 9).

variation of a geometric model (Fig. 9) for desired conditions, by means of the generation program and using the available list of standard parts (rolling elements, lubrication system, distance rings, bolts, etc.).



Sl. 9. *Spreminjanje dimenzij geometrijskega modela.*
Fig. 9. *Dimension variation of geometric model.*

Iz geometrijskega modela se izdela dokumentacija za posamezne nestandardne sestavne elemente in programe za numerično krmiljeno proizvodnjo. Za izdelavo so pomembni tako geometrijski modeli — eksplicitne informacije, ki upoštevajo priporočila različnih predpisov in standardov (hrapavost, simboli geometrijskih elementov itn.), kakor tudi implicitne informacije, ki pomenijo nestandardizirana znanja o načinu in parametrih obdelave, vpenjanju. Vse te informacije se nahajajo v podatkovnih bazah, ki vsebujejo strukture in podatke o organiziranosti, geometrijski obliki, funkcionalnosti, tehnoloških parametrih ter glavne in stranske funkcije, ki so dostopne v vseh stopnjah razvoja. Uporabljene so tako pri numerično krmiljeni proizvodnji kakor pri izrisu standardne dokumentacije, ki še vedno edina omogoča natančno vidno preverjanje postavljenih geometrijskih in tehnoloških zahtev. Iz tega izhaja, da je natančen popis oblikovnega modela in prenos podatkovne baze v numerično krmiljen sistem bistven za izdelavo kakovostnih vrtljivih zvez.

The geometric model is then the basis for the creation of documentation for nonstandard parts and NC programs. Both are important for production, the geometric models - explicit information, taking into account recommendations of various regulations and standards (roughness, geometric elements symbols..) as well as implicit information — non-standardized knowledge about the methods of machining, its parameters, fixing. The sources of all this information are data bases containing structures and data on organization, geometry, functionality, technological parameters, as well as the main and auxiliary functions available in all stages of development. They are used in numerically controlled production as well as in the creation of classic documentation, which is still the only means of exact visual inspection of the set geometric and technological requirements. Consequently, it could be said that an exact definition of the geometric model and the transfer of the data base to the NC system is essential for the production of high quality rotational connections.

4. SKLEP

Proizvodnja ležajev za vrtljive zveze je pri nas v Sloveniji kakor tudi po svetu precej individualna. Ob primerni tehnološki opremljenosti proizvodnje so glavni problemi razvoj in konstruiranje ter priprava proizvodnje.

Razvoj programskega sklopa na temelju znanja za snovanje in konstruiranje vrtljivih zvez je pokazal, da je to uspešna pot za izboljšanje kakovosti in učinkovitosti standardnih sistemov računalniško podprtega konstruiranja, ki jih je mogoče dopolniti do mere, da je omogočen celoten pretok informacij tehničnega modela od snovanja do dimenzioniranja, krmiljene proizvodnje in izdelave

4. CONCLUSION

The production of bearings for rotational connections is largely individual. When suitable technological equipment is available, the main problems are development, design, and preparation of production.The development of a knowledge-based program package for the planning and design of rotational connections has proved this to be a successful way to improve the quality and efficiency of conventional CAD systems. They can be adapted to such an extent that a complete technical model information flow, through planning, dimensioning, NC controlled production and creation of technical documentation, is provided.

tehnične dokumentacije. Namen programskega sistema ni popolna nadomestitev strokovnjaka – konstrukterja, pač pa je namenjen kot pomoč pri razvojnem procesu, saj so nekatere odločitve pri izboru ponujenih mogočih rešitev prepuščene prav njemu. Programski sklop mu poveča preglednost rešitev glede na podane robne pogoje in mu omogoča bistveno večjo učinkovitost.

The program system is not meant to fully replace an expert – designer, but it should be regarded rather as an aid in the development process since some decisions in the selection of possible solutions available are always up to the designer. The program package only increases overview of the possible solutions with regard to the given boundary conditions, and facilitates essentially higher efficiency.

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