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Antropoidne merilne naprave v koordinatni merilni tehniki
Anthropoidic Measuring Devices in Coordinate Measuring Techniques

IGOR KOVAČ

Popolna integracija koordinatne merilne tehnike v proizvodnjo je bila pogosta tema obravnav, vendar je do sedaj vedno naletela na omejitve. Popolnoma nova pot se odpira z uvajanjem prenosnih koordinatnih merilnih naprav (KMS). Raziskave na področju lahkih antropoidnih merilnih naprav obetajo eno od možnih rešitev tega problema. Pri tem gre za koordinatno merilno napravo z rotacijskimi osmi brez lastnega pogona, pri katerih je težišče prizadevanj usmerjeno v izboljšanje ponovljivosti in absolutne natančnosti, ki pomenijo na tem področju pomemben prispevek. Poleg obravnave konstrukcijskih značilnosti merilne naprave analiziramo v članku problematiko kalibriranja in merjenja antropoidnih naprav in podajamo možnosti za praktično uporabo.

Ključne besede: metrologija, naprave merilne koordinatne, testiranje lastnosti, kalibriranje

The full integration of coordinate measuring techniques into the production process has always been propagated, but it faces its limits. The completely new way can enable to obtain a coordinate measuring device which is portable. In this respect, the approach of light anthropoidic measuring devices may represent the promising solution. Here we are dealing with a coordinate measuring device of exclusively rotational axes without any drive system, in which the design details of repeatability and absolute accuracy optimisation represent an important contribution. In the paper we discuss the design of the measuring device, problems of calibration and measurement of anthropoidic measuring devices, and also present some new possibilities of application.

Keywords: metrology, coordinate measuring devices, performance testing, calibration

0 UVOD

Kakovost proizvodnje je v industrijskih državah postala eden od odločilnih dejavnikov uspešnega pojavljanja na trgu [1]. Proizvodne usmeritve nedvomno vodijo k zmanjševanju števila obdelovancev v eni seriji, hkrati pa k povečevanju raznovrstnosti obdelovancev. Tako zavzemata prilagodljivost in kakovost izdelave zelo pomembni mesti na vseh ravneh industrijske proizvodnje. To nedvomno velja tudi za proizvodno merilno tehniko.

V velikoserijski proizvodnji opravljamo geometrijske meritve s posebej izdelanimi, za določeno uporabo prirejenimi večmestnimi merilnimi sistemi [2]. Ti merilni sistemi opravljajo merilne naloge največkrat avtomatsko, zelo hitro in natančno. Sistemi so zelo robustni in neobčutljivi na vplive iz okolice. Glavni razlog, da večmestnih merilnih sistemov ne moremo uspešno uvesti in uporabiti v srednje ali maloserijski proizvodnji, je njihova majhna prilagodljivost.

V proizvodnem strojništvu so za geometrijske meritve obdelovancev uspešno uveljavljeni univerzalni koordinatni merilni stroji KMS [3]. Glavne prednosti teh strojev se kažejo v prostem programiranju, univerzalni uporabi in veliki natančnosti merjenja, še posebej, če so meritve izvedene v temperaturno nadzorovanem okolju. Zahtevana velika natančnost sistema je zagotovljena že s konstrukcijo, ki je izvedena zelo togo s translacijskimi osmi v kartezičnih koordinatah in z lastno merilno mizo. Tak stroj je zelo težak. Možnost,

0 INTRODUCTION

In industrial countries, quality of production becomes the crucial criterion for successful competition on the market [1]. Trends in automatic production lead to decreasing the series size and at the same time to increasing the workpiece variety. Therefore, flexibility and manufacturing precision become important requirements at all levels of the manufacturing industry. Both are also crucial for the production measuring techniques.

In large series production the measurements are performed automatically with specially designed, application specific, multiple sensor measuring systems [2]. These measuring systems carry out measuring tasks with great speed and accuracy under common production environment conditions. On the other hand the poor flexibility of such systems is the main reason why this measuring system is not appropriate for use in medium or small series production.

Usually geometrical measurements in manufacturing systems are carried out by universal Cartesian measuring machines, i.e. CMMs [3]. The striking features are free programming, universal application and high accuracy, especially if the measurements are carried out under controlled environment conditions. The demanded high accuracy can be achieved through the rigid construction of translational axes in the Cartesian coordinate system and its own table. Such machines are extremely heavy and cannot be easily transported to the place of

da bi ga prenesli in postavili na samo mesto merjenja, je tu izključena. S takim strojem tudi ne moremo meriti obdelovancev neposredno v vpetju na stroju.

Z namenom, da bi povečali hitrosti merjenja in postavili KMS v delavniško okolje, so bili razviti tako imenovani "merilni roboti" [4]. Najpogosteje so opremljeni s tremi translacijskimi numerično krmiljenimi osmi. Od običajnih KMS se razlikujejo le v podrobnostih. Vendar je že v zasnovi predpostavljena trdna postavitev in s tem onemogočena prenosljivost.

Popolnoma novo dimenzijo v merilni tehniki vpeljuje zamisel, pri kateri ima prenosljivost merilne naprave najvišje prednostno mesto [5]. Tako nas je zamisel prenosne koordinatne merilne naprave vodila v raziskovalni projekt, pri katerem smo razvili prenosno merilno napravo z rotacijskimi osmi, imenovano antropoidna merilna naprava AMG-1. Rešitev takega merilnega stroja z izključno rotacijskimi osmi ni nova. Nekatere najbolj značilne so navedene v preglednici 1.

measurement. Because of their configuration the CMMs cannot be appropriate for measurements directly made on the machine fixture.

To make the CMMs faster and more convenient for workshops, the so called "measuring robots" [4] were developed. They have mostly three translational numerically controlled axes. The difference from the common CMMs is found only in some details. However, these instruments require a fixed installation place, and are not portable to the place of measurement.

A completely new dimension in the measuring techniques is introduced by the concept in which portability has the highest priority [5]. This idea has led to tha research project in which the new portable anthropoidic measuring device AMG-1 was developed. The solution of the measuring machine with the rotational axes is not new. Nevertheless, there are only some measuring devices with special kinematics. Some of these are listed in Table 1.

Preglednica 1. *Antropoidne koordinatne merilne naprave*
Table 1. *Anthropoidic coordinate measuring machines*

Merilna naprava: Measuring device:	Osi/Axes	Masa/Mass kg	Natančnost/Accuracy mm	Premer krogle Sphere Diameter mm
MicroScribe-3D	5	-	0,51	1275
Romer 2200	6	11	0,06	2200
Addison Addata-Plus	5	-	-	-
Faro Metrecom	6	13	0,07	1800
Poly	6	-	-	-

Že bežen pregled značilnosti naštetih merilnih naprav pove, da naštete naprave ne dosegajo natančnosti, ki se zahtevajo pri merjenju v proizvodni merilni tehniki. Če želimo vpeljati antropoidne merilne naprave v koordinatno merilno tehniko proizvodnega strojništva, moramo najprej izboljšati absolutno natančnost same naprave. V ta namen smo se na Fakulteti za strojništvo, Univerze v Mariboru v sodelovanju z Inštitutom za proizvodno strojništvo, Tehniške univerze v Gradcu iz Avstrije lotili znanstvene obravnave navedene problematike.

From a brief survey of performances of the above mentioned measuring devices it is already evident that not all of the devices have the expected accuracy for measurement in production manufacturing technology. If we wish to introduce such devices into the measuring technology of production manufacturing, the absolute accuracy has to be increased. At the Faculty of Mechanical Engineering, University of Maribor - and in cooperation with the Institute for Production Engineering, Technical University Graz, Austria - we proceeded in dealing with the above problems.

1 NOVA PRENOSNA MERILNA NAPRAVA

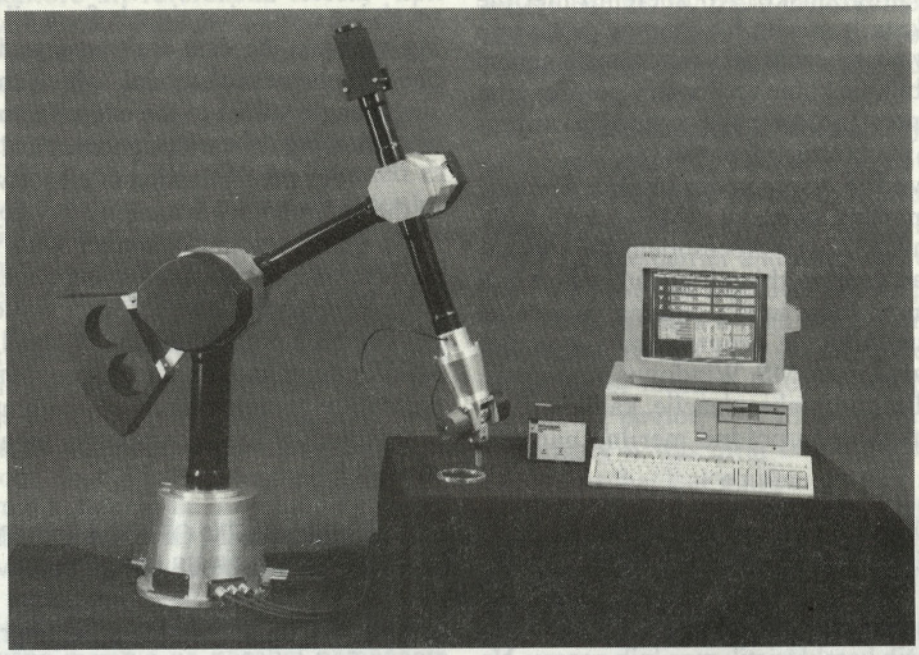
Antropoidna merilna naprava AMG-1 na sliki 1 je prenosna koordinatna merilna naprava brez lastnega pogonskega sistema. To pomeni, da jo na določeno mesto lahko prinesemo, postavimo in izvedemo potrebno meritev. Pri merjenju premikamo antropoidno merilno napravo ročno ali z uporabo industrijskega robota. Samo ime "antropoidna" ponazarja njeno konfiguracijo, ki jo sestavljajo samo rotacijske osi. Da dosežemo vse položaje in usmeritve v želenih točkah merjenja, potrebujemo najmanj pet

1 A NEW PORTABLE MEASURING DEVICE

The anthropoidic measuring device AMG-1 in Fig. 1 is a portable coordinate measuring device without its own drive system. It means that it can be brought to the place where the measurements have to be done. The movement is carried out by hand or by an industrial robot. Even its name "anthropoidic" indicates that it involves a configuration with exclusively rotational axes. To attain all degrees of freedom for a given measuring problem, at least five axes are needed: three for positioning and two for orien-

prostostnih stopenj: tri lege in dve usmeritvi. Konfiguracija, ki zajame največji delovni prostor ob najmanjši velikosti mehanske strukture, dosega majhno težo in veliko stopnjo prilagodljivosti. Merilno napravo lahko uporabimo v naslednjih primerih:
- ročna, prenosna koordinatna merilna naprava,
- robotsko vodena koordinatna merilna naprava,
- naprava za testiranje industrijskih robotov.

tation. With this configuration, which gives the maximum of work space with the smallest size of mechanical structure, we can achieve low weight and a high level of flexibility. The anthropoidic measuring device AMG-1 is foreseen for three different application fields:
- manual, portable coordinate measuring device,
- robot guided coordinate measuring device,
- testing device of industrial robots.



Sl. 1. *Antropoidna merilna naprava AMG-1*
Fig. 1. *Anthropoidic measuring device AMG-1*

V primeru geometrijskih meritev opremimo antropoidno merilno napravo z dotikalnim tipalom. Pri vodenju antropoidne merilne naprave z industrijskim robotom potrebujemo pri AMG-1 dodatno usmerjevalno os. Ker pa pri geometrijskem merjenju vrtenje okoli same osi tipala nima nikakršne praktične vrednosti, kotni merilni sistemi v tej osi niso vgrajeni.

Ključni element AMG-1 so kotni merilni sistemi velike natančnosti [6]. Za položajne osi smo izbrali modularno izvedbo kotnih merilnih sistemov s 36000 črticami na zasuk. Po interpolaciji znaša kotna resolucija položajnega dela 0,0325" in resolucija usmerjevalnega dela 0,127". Resolucija, preračunana na vrhu naprave, ko je ta 1200 mm oddaljen od izhodišča koordinatnega sistema podstavka, je v vsem delovnem prostoru boljša od enega µm. Znatne izboljšave so bile dosežene s statičnim uravnoteženjem s protiutežmi in z minimizacijo vpliva upogibanja, kar prinese tudi ugodnosti pri programski izravnavi elastičnih deformacij zaradi lastne teže. Za dosego potrebne merilne natančnosti je napravo AMG-1 treba kalibrirati in kompenzirati [7].

In the case of geometrical measurements, we equip the anthropoidic measuring device with a touch trigger probe. In movement with an industrial robot in all six degrees of freedom case, the AMG-1 is equipped with the sixth axis in the orientation part. Since there is no practical need for the ball probe to be rotated along its own axis, this axis has no angle measurement system.

The main part of AMG-1 constitute the most accurate angle-measuring systems (encoders) available [6]. For the positioning axes modular angle encoders with 36000 lines per rotation were selected. After interpolation, the angle resolution of the positioning part is 0.0325" and the resolution of the orientation part 0.127". Resolution calculated for the top of the end-effector, which is 1200 mm away from the centre, is always smaller then 1 µm. Considerable efforts have been made to achieve fine balancing with counterweights and to minimize deflections. This also brings benefits for the software compensation of elastic deformations under the machine's own weight. To achieve the necessary measuring accuracy, the anthropoidic measuring device had to be calibrated and compensated [7].

Elektronski del merilne naprave sestavljajo vmesniške kartice IK 121, ki spreminjajo analogne signale v obliki sinusne funkcije v digitalne kotne vrednosti, primerne za nadaljnjo obdelavo na osebnem računalniku. Kartica vključuje tudi interpolacijsko elektroniko, ki na eno vhodno signalno periodo pripravlja 1024 kotnih vrednosti. Pri tem je pomembno, da elektronski sistem omogoči hkratno shranjevanje vseh vrednosti števca. Shranjevanje podatkov lahko sprožamo prek zunanjega stikalnega tipala, z uporabo referenčnega signala ali pa programsko. Ko zberemo merilne signale vseh kotnih merilnih sistemov, vstavimo vrednosti kotov posameznih osi v razviti matematični model, ki preoblikuje kotne vrednosti v položaj vrha antropoidne merilne naprave z upoštevanjem najrazličnejših geometrijskih napak [8].

Za izvedbo vseh programskih funkcij antropoidne merilne naprave AMG-1 zadostuje osebni računalnik s 33 MHz procesorjem 486 s štirimi vmesniškimi karticami za zbiranje podatkov koračnih merilnih sistemov. Programska oprema, ki teče na osebnem računalniku, je programirana v jeziku Borland Pascal 7,0 za MS Windows in vsebuje funkcije inicializacije, sinhronizacije, kalibracije in zbiranja podatkov antropoidne merilne naprave AMG-1 [9].

2 PROBLEMATIKA MERJENJA IN REZULTATI PRESKUŠANJA

Merilna negotovost pomeni nedvomno eno najpomembnejših karakteristik merilnih naprav. Na področju preizkušanja merilnih naprav z vrtilnimi osmi za zdaj še ni izdelanih ustreznih mednarodnih standardov ali smernic. Prav tako je tudi stanje glede izbire metode in opreme za merjenje še precej neurejeno.

Merilne naprave z izključno vrtilnimi osmi zaradi svoje mehanske sestave močno spominjajo na zgibne industrijske robote. Tako je primerno preučiti znane testne metode in opremo, ki se uporablja v primeru testiranja karakteristik industrijskih robotov [10]. Pogoj, da je treba med samim potekom meritve ročno vodene antropoidne merilne naprave premikati z zunanjim sistemom vodenja, ovrže možnost uporabe katerekoli od znanih metod merjenja industrijskih robotov.

Ker gre za merilno napravo, je upravičeno, da jo obravnavamo kot običajni koordinatni merilni stroj. V ta namen smo preučili postopke in metode merjenja, ki so običajni za to področje tehnike [11]. Preučitev je pokazala, da je merjenje merilne negotovosti antropoidnih merilnih naprav, pri katerih je vključeno tudi tipalo, lahko enako kakor pri kartezičnih koordinatnih merilnih strojih. Vendar pa določitev posameznih parametrov matematičnega modela mehanizma z vrtilnimi osmi ter dodatna potrditev njegove ustreznosti, zahteva poseben

The electronic part of the measuring device used is the interface card IK 121, which transforms the analog signals with sinusoidal wave function to digital angle values suitable for further processing on the PC. The interface card includes also the interpolation electronic circuit which generates 1024 counts per input signal period. It is very important that the electronic system allows for simultaneous storage of all counter values. The data storage can be latched by an external signal over a touch trigger probe, over a reference signal or by software. After receiving measuring signals from all angle measuring systems, the data are transferred to the developed mathematical model, which transforms the single angle values to the end-effector position values, allowing for various geometrical errors [8].

For the realization of all software functions of the anthropoidic measuring device AMG-1, a 33 MHz 486 personal computer with four interface cards for incremental measuring systems data acquisition is provided. The software, which runs on the PC, has been programmed in Borland Pascal 7.0 for MS Windows and consists of program parts for initialization, synchronization, calibration and data acquisition of the anthropoidic measuring device AMG-1 [9].

2 PROBLEM OF MEASUREMENT, AND RESULTS OF EXPERIMENTS

The most important characteristic of a measuring device is the measuring uncertainty. There are no international standards or guidelines for testing of measuring devices with rotational axes. There is also unclear, which measuring method and measuring equipment should be selected.

As long as the measuring devices with exclusively rotational axes are mechanically configured as an industrial robot, we could still use the known related test methods and available equipment from the field of robot performance identification [10]. The problem is that, while the measurements are being carried out the manually guided measuring devices have to be moved by an external carrier. For solving such a problem no suitable measuring equipment is yet available on the market.

The measuring devices with rotational axes might be considered as usual coordinate measuring machines. For this purpose the experiences and methods of such techniques have been taken into consideration [11]. Assessment of measuring uncertainty of the whole anthropoidic measuring device with a probe can be completely the same as that performed by the Cartesian coordinate measuring machine. However, the determination of the single parameters of the mathematical model of mechanisms with revolution axes and its verification requires a special approach, special measuring method and special equip-

postopek, posebno merilno metodo in posebno opremo, kakršno poznamo za merjenje kartezičnih koordinatnih merilnih strojev.

Kakor smo omenili, antropoidna merilna naprava nima lastnega pogona. Zato je treba zagotoviti neodvisen sistem vodenja, ki pri merjenju prevzame funkcijo pozicioniranja s predpisano ponovljivostjo. Tako optični merilni sistemi, kakor so npr. sistem merjenja z uporabo kamer, laserski sledilni sistem ali pa teodolitni sistem za zastavljeno nalogo niso primerni. V praksi proizvajalci uporabljajo kalibre ali referenčna telesa, npr. referenčno ravnilo, kalibrirni obroč ali pa kalibrirno kroglo. Tudi v tem primeru problem vodenja ni rešen, poleg tega pa rezultat meritve vsebuje tudi vpliv tipala, ki ni zanemarljiv.

V primeru merjenja ponovljivosti z uporabo natančnega KMS Zeiss UMC 850 na Fakulteti za strojništvo v Mariboru, smo vrh antropoidne merilne naprave AMG-1 mehansko povezali z merilno glavo KMS, ki je rabila obenem kot vodilo in kot referenčni merilni sistem. Po analizi prvih meritev smo ugotovili, da so rezultati zaradi velikega raztrosa merilnih vrednosti neuporabni. Vzroki za odstopanja ležijo v elastičnem upogibanju konstrukcije KMS zaradi vodenja antropoidne merilne naprave. Iz te izkušnje izhaja, da je zahtevano natančnost merilnega sistema mogoče doseči le z robustno mehansko merilno opremo, ki temelji na merjenju in vodenju vzdolž referenčne ravne črte, ki jo v prostoru tako glede lege - kakor glede smeri lahko poljubno nastavljamo.

Da bi navedene domneve lahko potrdili, smo izvedli poskusne meritve na posebej natančnem dolžinskem merilnem sistemu v klimatiziranem prostoru v laboratorijih Inštituta za obdelovalno tehniko Tehniške univerze v Gradcu v Avstriji (sl. 2) [12]. Referenčno ravnilo dolžinskega merilnega sistema je granitni blok. Po njem se pomika gnani zračno vležajen voziček. Kot dolžinski referenčni sistem je uporabljen laserski interferometer. Na tem posebno natančnem dolžinskem merilnem sistemu smo izvedli meritve ponovljivosti in natančnosti. Pri meritvah smo merilno napravo AMG-1 postavili na pripravljeno togo podlago. Šesta os na vrhu merilne naprave je bila priključena na zračno vležajeni voziček. Na ta način smo ponovitve položajenja merilne naprave AMG-1 v programiranih položajih izvedli povsem avtomatsko.

Testne položaje smo izbrali vsakih 100 mm vzdolž ravnila in sicer od -900 do 900 mm v smeri osi x. Na sliki 3 je prikazana srednja vrednost položajne ponovljivosti antropoidne merilne naprave AMG-1, ki je določena na osnovi več kot petdesetih ponovitev v posameznem položaju vzdolž osi x.

Na sliki 3 je tudi dobro razvidna odvisnost ponovljivosti od oddaljenosti vrha antropoidne merilne naprave glede na njen osnovni koordinatni sistem. Zaradi strukture sedanjega dolžinskega merilnega sistema ni bilo mogoče meriti še na drugih višinskih ravneh in v poljubnih prostorskih smereh.

ment, such as we are familiar with for the measurement of the coordinate measuring machines.

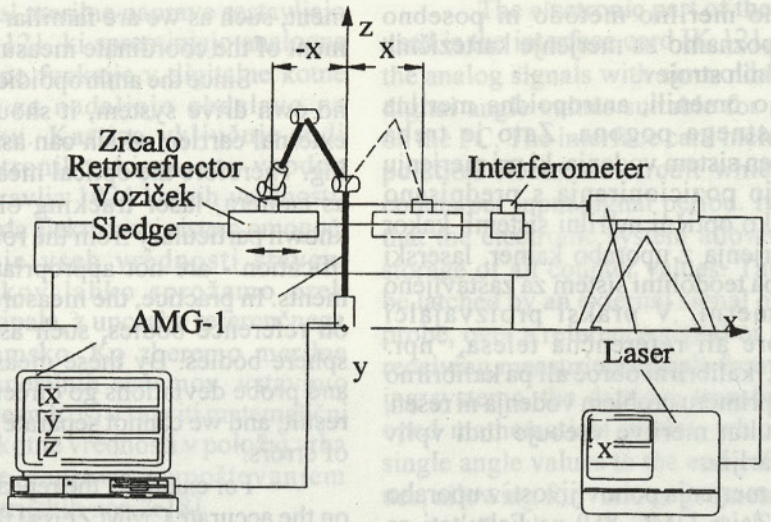
Since the anthropoidic measuring device has no own drive system, it should be moved with an external carrier, which can assure repeatable guiding. Therefore the optical measuring systems - such as camera, laser tracking or theodolite systems, known particulary from the robot performance identification - are not appropriate for these measurements. In practice, the measurements are carried out on reference bodies, such as line gauges, ring or sphere bodies. By these measurements all guiding and probe deviations go directly into the measuring result, and we cannot separate these different causes of errors.

For example, the repeatability measurements on the accurate CMM Zeiss UMC 850 at the Faculty of mechanical engineering in Maribor - where the anthropoidic measuring device AMG-1 and the CMM, as the carrier and reference measuring system, were coupled together - did not prove to be useful. There appears a high dispersion of measuring results caused by CMM system deflection as a consequence of reaction forces when pushing such a measuring device with rotational axes. From this experience it was clear that measurements with a robust mechanical equipment (for measuring and guiding along any reference line adjustable in the space) can represent the only correct high precision solution, which can be taken as an appropriate reference measuring system.

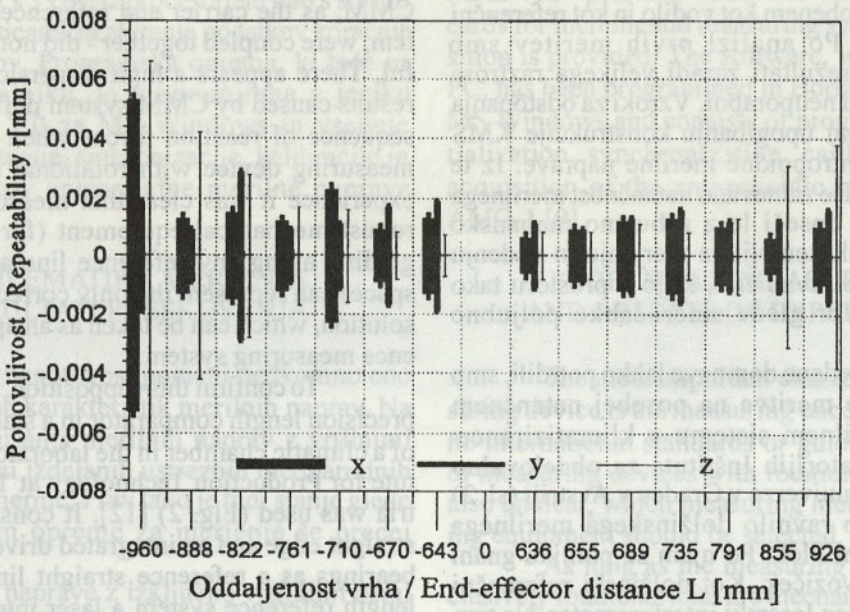
To confirm this supposition, the existing high precision length comparator in a stable environment of a climatic chamber in the laboratories of the Institute for Production Technology at TU Graz in Austria was used (Fig. 2) [12]. It consists of a granite straight edge and an integrated drive sledge with air bearings as a reference straight line system. As a length reference system a laser interferometer system was used. On this high precision length comparator repeatability and accuracy measurements of the anthropoidic measuring device were performed. Following these measurements the AMG-1 was put onto the prepared frame. The sixth axis of the end effector was coupled to the drive sledge. The repeated positioning of the measuring device AMG-1 at the particular point was carried out automatically.

Along the straight edge the test poses in x direction were chosen every 100 mm from -900 mm to 900 mm. After more than fifty repetitions at each point, the middle value of the positioning repeatability in each position along x axes of the anthropoidic measuring device AMG-1 is presented in Fig. 3.

It can be seen that the repeatability depends strongly on the positioning distance at which the center point of the anthropoidic measuring device AMG-1 is situated. Due to the structure of the existing measuring equipment it was not possible to measure at other levels and in other directions.



Sl. 2. *Posebej natančno dolžinsko ravnilo*
Fig. 2. *High precision length comparator*



Sl. 3. *Ponovljivost položajenja AMG-1 v odvisnosti od oddaljenosti vrha*
Fig. 3. *Repeatability of positioning of AMG-1 regarded to its end-effector distance*

Tovrstne meritve so nepogrešljive tudi pri kalibracijskem merjenju. Z vidika merilne opreme je kakovost procesa kalibracije odvisna predvsem od natančnosti zbiranja, števila in porazdelitve posameznih merilnih točk v delovnem prostoru naprave, ki jo merimo. To pomeni, da mora merilni sistem posebne natančnosti omogočiti nastavljanje referenčne črte na različnih višinah in v poljubni smeri v prostoru.

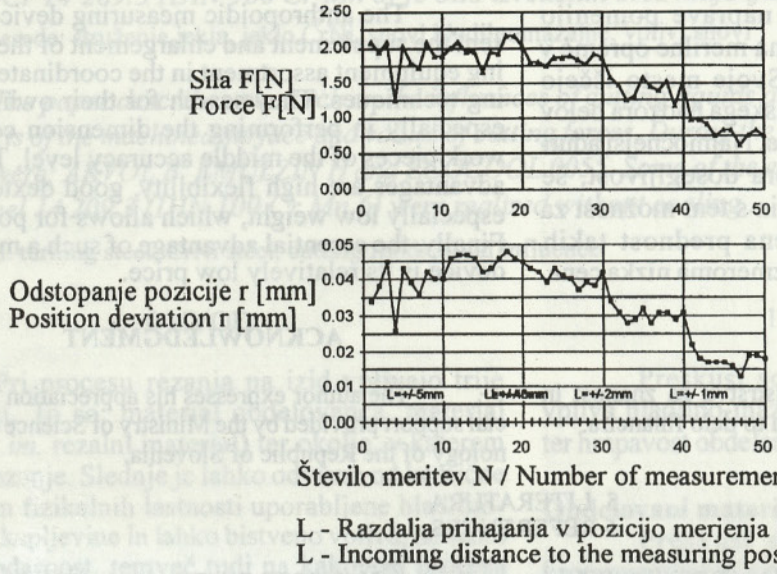
Sile, ki se pojavljajo pri premikanju vrha antropoidne merilne naprave, se zaradi členkaste kinematične konfiguracije stalno spreminjajo. Odvisne so od trenutnega položaja in usmeritve vrha naprave. Za členkaste mehanizme je značilno, da se sile in momenti, potrebni za premik v območju singularnosti, lahko čezmerno zvečajo. Tako se pojavi upogibanje merilne naprave, ki pokvari merilni rezultat. V ta namen smo raziskali vpliv sil in

Such measurements are indispensable also for calibration measurements. The quality of a calibration from the equipment point of view depends, moreover, on the number and distribution of measuring positions in the particular working space of the measured device. This requirement leads to the design of a new reference measuring system of higher accuracy which could be adjustable at different levels and in different directions.

Because of the anthropoidic kinematic configuration of the measuring device, the end-effector moving forces change permanently. They depend on a momentary mechanical configuration. Especially movements in the area, which is close to the singularity, cause higher moving forces and moments. If it is a matter of coordinate measurements, these forces and moments can distort the measuring result. So it is important to investigate the influence of moving

momentov, ki se pojavljajo pri premikanju antropoidne merilne naprave. S tridimenzionalnim zaznavalom sil smo izvedli meritve poteka sil pri premikanju AMG-1. Rezultati teh preskusov kažejo zelo dobro medsebojno zvezo sil med premikanjem z odstopki položaja antropoidne merilne naprave (sl. 4). Preskus je tudi pokazal, da sile, ki se pojavijo pri premikanju v različnih smereh v prednostnem področju delovnega prostora antropoidne merilne naprave, ne presegajo vrednosti 5 N.

forces and moments from the device to be measured. For this problem we took a 3D force sensor and made the comparison measurements with AMG-1. The results of this experiment show very good correlation between the moving force and the position deviation of the anthropoidic measuring device (Fig.4). It was also noticed that the moving force in the favourable part of the measuring space in different measuring positions from different directions does not exceed the force of 5 N.



L - Razdalja prihajanja v pozicijo merjenja [mm]
L - Incoming distance to the measuring position [mm]

Sl. 4. *Odstopanje sile in položaja AMG-1 pri prihajanju v položaj merjenja*
Fig. 4. *Position and force deviation of AMG-1 by incoming in to the measuring position*

Preskusi kažejo, da antropoidna merilna naprava AMG-1 z razvitim kinematičnim modelom in izvedenim postopkom kalibracije in kompenzacije, lahko doseže različne položaje z dokaj veliko stopnjo natančnosti. Tako leži ponovljivost v področju mikromilimetrov. Absolutna natančnost je trenutno v področju stotink milimetra. Preskusi so pokazali, da na absolutno natančnost še vedno vplivajo najrazličnejši viri odstopanj, ki so sistematične narave in jih je mogoče programsko nadomestiti.

The experiments show that the anthropoidic measuring device AMG-1, with the developed kinematic model and the executed calibration and a compensation step, can collect different positions with high positioning performance. The repeatability lies in the micro millimetres area. The absolute accuracy is situated in the hundredth-millimetres area. Additional experiments show that the absolute accuracy is still influenced by sources of systematic errors and can be compensated by software.

3 NOVE MOŽNOSTI UPORABE

Antropoidne merilne naprave so popolnoma nova smer v merilni tehniki. Odpirajo se možnosti merjenja neposredno v vpetju na obdelovalnem stroju. Antropoidno merilno napravo lahko prinesemo na mesto merjenja. Merilna tehnika s tem pridobi novo, lahko, prenosno merilno napravo. Prednost prenosljivosti merilne naprave pomembno razširi področje uporabe. S tako napravo preprosto merimo majhne npr. montažne dimenzije na zelo velikih obdelovancih. Napravo lahko postavimo v posodo in merimo njeno notranjost. Enako velja za merjenje kupol ali pa notranjosti avtomobila. Antropoidne merilne naprave lahko s pridom uporabimo za testiranje ergonomskih mer. Naslednja možnost je merjenje prosto oblikovanih površin. Tudi

3 NEW POSSIBILITIES OF APPLICATION

The anthropoidic measuring devices represent a completely new approach in measuring techniques. For the first time, one is able to make direct measurements in the machine fastening device, and it is possible to bring the measuring device to the place of measuring. The measuring technique gets the new, light and portable measuring device. The advantage of measuring device portability can lead to the considerable expansion of its use, for example in the measurement of small (mounting) dimensions on very big work pieces. There is no problem in measuring the inner space of containers, cupolas, car bodies, etc. The ergonomic measurements can be tested very accurately. The next possibility is also that of measuring the free formed surfaces or curved

meritve ukrivljenih cevi v prostoru ne pomenijo posebnih problemov. Premikanje antropoidne merilne naprave lahko prepustimo industrijskim robotom [13]. V taki povezavi je mogoče opravljati geometrijske meritve obdelovancev v prilagodljivem obdelovalnem sistemu ali pa testirati lastnosti industrijskih robotov [14].

pipe lines. Another application field of the anthropoidic measuring device is in connection with the industrial robot [13]. It is possible to measure the geometrical dimensions of work pieces in a flexible manufacturing system. On the other hand, the anthropoidic measuring device can also be used for measurements of robot accuracy performances [14].

4 SKLEP

Antropoidne merilne naprave pomenijo dopolnitev in razširitev programa merilne opreme v koordinatni merilni tehniki. Svoje mesto iščejo predvsem pri izvajanju dimenzijskega nadzora delov srednjega natančnostnega razreda. Najmočnejši aduti so velika prilagodljivost, dobra dosegljivost, še posebej pa majhna teža naprav in s tem možnost za prenos. Kot zadnja in bistvena prednost takih merilnih naprav pa je njihova razmeroma nizka cena.

4 CONCLUSION

The anthropoidic measuring devices represent the supplement and enlargement of the measuring equipment assortment in the coordinate measuring techniques. They search for their own position especially in performing the dimension control of work pieces of the middle accuracy level. The main advantages are high flexibility, good dexterity and especially low weight, which allows for portability. Finally, the essential advantage of such a measuring device is its relatively low price.

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