Programiranje kretanja industrijskog robota

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Promene u svetskom prometu roba i usluga, usmerene ka globalizaciji tržišta i želja proizvođača da ispune zahteve svakog pojedinačnog kupca, nameću sve strožije zahteve postojećim tehnološkim sistemima. Primena robotskih sistema u montaži značajno unapređuje performanse takvog tehnološkog sistema, smanjuje vreme montaže, povećava produktivnost i kvalitet montiranih proizvoda. U radu je prikazana primena programskog paketa RobotStudio za programiranje rada robota za montažu. Urađena je analiza tehnologije montaže podsklopa osovine koja je neophodna kako bi se u programskom paketu dobio kod po kojim se upravlja robotom.

Keywords: Robotski sistemi; tehnologija montaže;

1. UVOD

U današnje vreme svet se suočava sa ubrzanim razvojem nauke i tehnike i nalazi se u jednoj od faza koje često nazivamo fazama revolucionarnih promena. Razvoj tehnike i sredstava za proizvodnju nije bio ravnomeran. Smenjivali su se periodi ubrzanog razvoja i relativne stagnacije. Najpoznatiji skok u razvoju, poznat pod imenom industrijska revolucija, nastupio je krajem osamnaestog i početkom devetnaestog veka. Počelo je 1733. godine sa pojavom mehanizovanog razboja za tkanje. Sledeći veliki pronalazak bila je parna mašina (1769.), a zatim je nastupio buran razvoj tehnike i sredstava za proizvodnju, odakle je i potekao naziv industrijska revolucija. Istorijski gledano, postoji još niz pronalazaka i naučnih dostignuća koji su bitno obeležili tehnički razvoj sveta u određenim periodima. Razvoj nauke i novih tehnologija, nagoveštavaju kvalitativne promene u oblasti proizvodnje i društvu uopšte [1]. Jedan od bitnih činilaca nove revolucije je fleksibilna automatizacija čiji nerazdvojni deo predstavljaju robotski sistemi. Ideja o robotima nastala je prvo u naučnoj fantastici. I danas, u diskusijama o robotskim sistemima i svemu što oni donose teško se mogu izbeći vizije iz oblasti naučne fantastike. Naravno, na robote se danas gleda mnogo praktičnije, jer stupanj razvoja tehnike to omogućava. To su veoma složeni uređaji koji su se mogli pojaviti kada su se razvile one grane nauke na kojima se današnja robotika zasniva: teorija mašina, teorija automatskog upravljanja, računarska tehnika, metode tzv. veštačke inteligencije, kao i tehnologija senzora i pretvarača. Na robote se danas gleda kao na uređaje koji omogućavaju dalju i fleksibilniju automatizaciju. Oni zamenjuju čoveka prvenstveno na opasnim, monotonim i teškim poslovima. Čoveku ostaju poslovi koji zahtevaju više inteligencije, znanja i kreativnosti. Tako, robotski sistemi doprinose istovremeno povećanju produktivnosti i humanizaciji rada.

Troškovi montaže proizvoda značajno utiču na ukupne troškove njegove proizvodnje a samim tim i na profit kompanije. To je jedan od razloga zašto je potrebno izvršiti unapređenje a u nekim slučajevima i reinženjering procesa montaže proizvoda metaloprerađivačke industrije. Na osnovu analize koja je sprovedena u sektoru montaže 355 nemačkih kompanija u mašinskoj industriji ukazuje se

na činjenicu da glavni potencijali racionalizacije leži u projektovanju proizvoda, koje je orjentisano na montaži, i u automatizaciji operacija montaže [2].

2. ANALIZA TEHNOLOGIJE MONTAŽE PODSKLOPA RAZVODNE OSOVINE

Podsklop koji se montira se sastoji od tela pumpe (poz.15), podsklopa razvodne osovine (poz.25), zaptivke (poz. 27 i 8), prstena (poz. 26), i podsklopa podmetača (poz. 24), slika 1.

Slika 1. Plan montaže podsklopa razvodne osovine

Podsklop razvodne osovine (slika 2) se sastoji iz: razvodne osovine (poz. 25), kuglice (poz. 23), dve zaptivke (poz. 27), opruge (poz. 16), vijka (poz. 18), podloške (poz. 17), zaptivke (poz. 20), i O-prstena (poz. 31).

Slika 2. Podsklop razvodne osovine (presek)

Razvodna osovina (poz. 25) je izrađena od CuZn20.00 (mesing), spoljašnje cilindrične površine se obrađuju struganjem a ravne (četvrtka) glodanjem. Rupe i otvori se izrađuju bušenjem a u zavisnosti od klase hrapavosti, proširivanjem i razvrtanjem. Upuštanje ivica otvora se izvodi čeonim i konusnim upuštaciima.

Dimenzije razvodne osovine su $\varnothing 18 \times 82,5 \text{ mm}$. Na razvodnoj osovinu se nalaze otvori $\varnothing 6/\varnothing 2,5$, $\varnothing 5,2/\varnothing 3$ i $\varnothing 3,5$ kroz koje prolazi radni fluid. To su otvori koji razvode radni fluid prema odgovarajućim otvorima na telu pumpe.

Slika 3. 3D model podsklopa razvodne osovine (presek)

Podsklop razvodne osovine izvršava ključnu ulogu upravljanja pumpom. U otvor $\varnothing 6$ se montira ručica pomoću koje se upravlja razvodnom osovinom, tj. rotira se razvodna osovina u odgovarajući položaj kako bi se omogućio protok radnog fluida kroz odgovarajuće ostore na razvodnoj osovinu i telu pumpe.

Telo pumpe (poz. 15) je od sintetičkog sivog liva bez oligo-elemenata (SL25). Ravne površine se obrađuju glodanjem. Rupe, otvori i upuštanje ivica se izvodi kao i kod razvodne osovine. Žleb se izrađuje glodanjem. Dimenzije tela pumpe su $80 \times 30 \times 130 \text{ mm}$. Otvor za montažu razvodne osovine je prečnika $\varnothing 16$, klase hrapavosti N6, koji je sa prednje strane proširen na $\varnothing 18$, dužine $17,5 \text{ mm}$ od ivice otvora koja je upuštena $1/15^\circ$. Između prečnika $\varnothing 16$ i $\varnothing 18$ je izrađen prelazni konus $1,8/45^\circ$. Druga strana otvora je upuštena $1,8/15^\circ$. Na tom otvoru su izrađeni i otvori za dovod i odvod radnog fluida.

Slika 4. 3D model tela pumpe

3. POKRETANJE I IZBOR ROBOTSKOG SISTEMA PROGRAMSKOM PAKETU ROBOTSTUDIO

Simulacija je izrađena u programskom paketu *RobotStudio* (dalje u tekstu *RS*), verzija 5.15.02, kompanije *ABB* čiji robot se i koristi. Nakon pokretanja programa, odaberimo *Create new station*, pa projekt *Empty station* (Slika 5).

Slika 5. Kreiranje novog praznog projekta

Prema zadatku koji robot treba da odradi odaberemo željenog robota za montažu. U našem slučaju to će biti robot *IRB 140*, iz serije malih industrijskih robota. *IRB 140* ima nosivost 6 kilograma. Namenjen je pre svega za poslove: montaže, pakovanja, čišćenja, rukovanja materijalom i dr. (Slika 6).

Slika 6. ABB robot IRB 140

Prilikom uvođenja robota u tehnološki sistem montaže treba sagledati niz tehničko-tehnoloških kriterijuma. Potrebno je obratiti pažnju na radni prostor robota koji je definisan od strane proizvođača [3] (Slika 9).

Slika 7. Radni prostor robota ABB IRB 140

Da bismo uveli model robota u radni prostor, u programskom paketu RS, potrebno je koristiti opciju *ABB library* te odabrati robota *IRB 140*. Nakon toga potrebno je uvesti u program postolje robota i sto na kome se odvija proces montaže. U RS koristimo opciju *Import Geometry* pomoću koje uvezemo modele stolova pretvorene u odgovarajućem formatu (.SAT). Uvezeni modeli se pozicioniraju u odnosu na koordinatni sistem robota (Slika 8; Slika 9).

Slika 8. Pozicioniranje uvezene geometrije

Slika 9. Pozicionirani stolovi u radnom prostoru

Nakon pozicioniranja u radnom prostoru, što je bitno da bismo znali gde se tačno koji objekt nalazi, postavljamo robotsku ruku *IRB 140* na prvi radni stol opcijom *Set position* (Slika 10) [5].

Slika 10. Pozicioniranje robota na radni stol

Potrebno je i postaviti na drugom stolu komponente koje se montiraju (slika 1). Kod postavljanja robota i odlučivanja oko pozicije radnog modela potrebno je voditi računa na maksimalni domet robota (*IRB140* ima maksimalni domet 810mm) pa ovaj robot može izvršiti proces montaže.

Robotska ruka ima mogućnost priključka raznih alata za montažu. Bitno je obratiti pažnju na centralnu tačku alata (engl. *TCP*; *tool center point*) tj. njen koordinatni sistem. U toj tački robot ima prihvat gde se postavljaju alati za montažu [4](Slika 11).

Slika 11. Prikaz TCP i priključka za alate.

4. PRIMENA PROGRAMSKOG PAKETA ROBOT STUDIO ZA ODREĐIVANJE PUTANJE ROBOTA ZA MONTAŽU PODSKLOPA RAZVODNE OSOVINE

Da bismo mogli „voziti“ robota po željenoj putanji montaže, moramo ga „naučiti“ gdje su te putanje. Treba sagledati tehnologiju montaže kako bi putanja robota pri montaži bila što jednostavnija. Glavna opcija RS-a za generiranje putanje robotske ruke je *Path*, *AutoPath*. Nalazi se u prozoru *Home*, u *RobotStadiu* (Slika 12)

Slika 12. AutoPath opcija za generiranje ruta

Nakon označavanja svih željenih putanja za montiranje, na redu je postavljanje osnovne orijentacije PKI alata za montažu. Odredili smo za tu poziciju da bude u liniji sa centralnom alatnom točkom robota. To je izvršeno na način da smo označili poziciju tj. metu broj 10 (Target 10), i pomoću alata *Modify Target*, *Set rotation*, odredili poziciju alata za montažu (Slika 13).

Slika 13. Postavljanje osnovne pozicije alata

Nakon postavljanja pozicije kao na Slici 13, potrebno je desnim klikom označiti tu istu poziciju (*target*) te iz padajućeg menija izabrati opciju za kopiranje orijentacije (*Copy Orientation*). Sledeći korak je označiti sve pozicije (*targete*) u padajućem meniju našeg radnog objekta (*workobject*) te desnim klikom otvoriti padajući meni i primieniti istu orijentaciju na celi skup (*Apply orientation*). Nakon ispravne osnovne orijentacije potrebni korak je ponovno označavanje svih pozicija alata za montažu (*targeta*) i upotreba opcije za proveru dostupnosti svih pozicija (*Reachability*). Proveru vidimo na Slici 14.

Dostupnošću svih pozicija robotske ruke, krećemo sa konfiguracijom putanje robotske ruke prema odabranoj putanju. To ćemo napraviti na način da označimo putanju robotske ruke iz kategorije *Path tools*, odabrati alat *Auto Configuration* (Slika 15). Nakon izbora konfiguracije putanje robota možemo ponoviti korišćenje alata *Auto Configuration* kako bismo videli simulaciju kretanja robota po zadatoj putanji.

Postupak se ponavlja za svaku putanju. Provere dostupnog kretanja i eventualne greške u kretanjima. Postoji mogućnost da robotska ruka, koristeći linearna kretanja ne može dostići željeni položaj.

Slika 14. Provera dostupnosti pozicija kretanja

Slika 17. Konfiguriranje kretnji robotske ruke

Tada je prva opcija da kretanje definišemo kao kretanje zglobova (*MoveJ ; move joint*). To se radi tako da odaberemo kretanje unutar problematične rute (*Move;Path*), te uz pomoć opcije za promenu instrukcija (*Modify instructions*) promenimo tip kretanja (*Motion type*) iz linearnog u zglobo (linear;joint), (Slika 20). U predstavljenoj opciji za menjanje instrukcija (*Modify Instructions*), moguće je menjati i brzinu kretanja robotske ruke.

Slika 20. Opcija za izmjenu instrukcija

5. IZRADA SIMULACIJE PROCESA MONTAŽE U PROGRAMSKOM PAKETU ROBOTSTUDIO

Nakon izrade putanja potrebno je izraditi simulaciju zadate montaže. Prvo je potrebno odabrati robotski sistem koji ćemo koristiti, u našem slučaju je to *IRB 140*. To radimo na način da pod *Home* delom *RS-a*, odaberemo opciju *Robot System*, te postavimo sistem za naš odabir robotske ruke. Sledeći korak je sinhronizacija sa virtualnim kontrolerom u *RS-u*. U programu pod delom *RAPID*, koristimo opciju *Synchronize to VC*, označivši sve opcije, pokrenemo sinhronizaciju (Slika 21)

Slika 21. Sinkronizacija virtualnog kontrolera

Nakon izvršene sinkronizacije, potrebno je postaviti redosled izvođenja montaže prema postavljenim putanjama. To se radimo pod delom programa *RS*, nazvanim *Simulation*. Odaberemo opciju *Simulation setup*. U novo-otvorenom prozoru, iz dela dostupnih ruta (*Available Procedures*) za montažu, prebacujemo rute u glavnu sekvencu robotske ruke (*Main Sequence T_ROB1*). Odabirom aktivnih zadataka (*Active Tasks*), označavanjem našeg, ranije kreiranog robotskog sistema, moguće odabrati izvršavanje glavne sekvence kontinualno ili samo jedan ciklus (Slika 22).

Slika 22. Glavna sekvenca simulacije

Nakon odabira ruta za izvršavanje glavne sekvence robotske ruke *IRB 140*, preostalo je samo pokrenuti proces simulacije montaže, jednostavnom naredbom *Play* iz simulacijskog dela programa *RS*. Robotska ruka izvršava montažu po zadanim putanjama, sa minimalnom greškom, velikom preciznošću i velikom brzinom.

6. ZAKLJUČAK

Primena robotskog sistema u procesu montaže značajno skraćuje vreme montaže a povećava produktivnost kompanije. Neophodno je analizirati tehnologiju montaže samog proizvoda kako bi robot najkraćim putem i na najbolji način odradio proces montaže. Samo programiranje robota je veoma jednostavno uz grafičku podršku u obliku slika koje na jednostavan način opisuju šta je potrebno uneti u program za simulaciju rada robota nakon čega se generiše kod za upravljanje radom robota.

U radu je razmatran proces montaže jednog podsklopa, ali ovaj proces programiranja robota se može primeniti za montažu cele ručne pumpe. Mogu se programirati dva robota koji rade simultano.

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The Motion Programming of Industrial Robots

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Changes in world trade of goods and services, geared towards the globalization of markets and the desire of manufacturers to meet the requirements of each individual customer, are imposing increasingly stringent requirements on existing technological systems. The application of robotic systems in the assembly significantly improves the performance of the technological system, reduces installation time, increases productivity and quality of the assembled product. This paper presents an application software package RobotStudio for programming operation of assembly robots. An analysis of the assembly technology was performed in case of distribution axle subassembly, which is necessary in order to obtain the programming code under which the robot is controlled.

Keywords: Robotic systems; assembly technology;

1. INTRODUCTION

Nowadays, the world is facing with the accelerated development of science and technology and it is placed in one of the stages we often call the stages of revolutionary changes. The development of technique and the means of production was not uniform. Periods of accelerated development and relative stagnation are alternated. The great leap forward, known as the Industrial Revolution, occurred in the late eighteenth and early nineteenth centuries. It began in 1733 with the advent of power loom. The next great invention was the steam engine (1769), after that is followed the rapid development of technology and the means of production, hence the name of the Industrial Revolution. Historically, there are a number of inventions and scientific advances that have marked the technical development of the world in certain periods. The development of science and new technologies, hint at qualitative changes in the field of production and society in general [1].

One of the important factors of the new revolution is the flexible automation in which robotic systems are an integral part. The idea of robots is originated first in the science fiction. Even today, discussions about robotic systems and everything they are bringing can hardly avoid the visions of science fiction. Today, robots are considered more practical, as the development of technique development that allows.

These are very complex devices and they were able to emerge when those branches of science on which today's robotics are based have evolved: machine theory, automatic control theory, computer technology, artificial intelligence as well as sensor and converter technology. Robots are now regarded as devices that allow further and more flexible automation. Primarily, they replace man in dangerous, monotonous and difficult jobs. Man is left on jobs that require more intelligence, knowledge and creativity. Thus, robotic systems contribute simultaneously to increasing productivity and humanizing of work. The assembling costs significantly affect the overall product cost and therefore the company's profits. This is one of the reasons why it is necessary to improve and sometimes reengineer the assembly production of the metal processing industry. Based on an analysis carried out in the assembly sector of 355 German companies in the

mechanical engineering industry, the main rationalization potentials lie in the design of assembly-oriented products and in the automation of assembly operations [2].

2. THE ANALYSIS OF DISTRIBUTION AXLE ASSEMBLY TECHNOLOGY

The mounting subassembly consists of the pump body (15), distribution axle subassembly (25), gaskets (27 and 8), ring (26) and washer subassembly (24), (Fig. 1).

Figure 1. Mounting plan of the distribution axle subassembly

The distribution axle subassembly (Fig. 2) consists of the distribution axle (25), balls (23), two seals (27), spring (16), bolt (18), washer (17), gasket (20) and O-rings (31).

Figure 2 The distribution axle subassembly (cross section)

The distribution axle (25) is made of CuZn20.00 (brass), the outer cylindrical surfaces are treated by scraping and flats (square) by milling.

Holes and openings are made by drilling, depending on the roughness class, expanding and turning. The chamfer of the opening edges are made by the front and tapered recesses. The dimensions of the axle are

Ø18h82,5mm. There are Ø6 / Ø2.5, Ø5.2 / Ø3 and Ø3.5 through which the working fluid passes. These are holes that distribute the working fluid to the corresponding openings on the pump body.

Figure 3. 3D model of the distribution axle subassembly (cross section)

The distribution axle subassembly plays a key role in pump control. A lever is mounted in the hole Ø6 to control the distribution axle, i.e. the distribution axle is rotated to the proper position to allow the flow of the working fluid through the corresponding opening on the axle and pump body.

The pump body (15) is made of synthetic gray cast iron with no oligo elements (SL25). Flat surfaces are machined. The holes, openings and chamfers are performed as the same way as for the distribution axle.

Figure 4. 3D model of body pump

The groove is made by milling. The dimensions of the pump body are 80x30x130mm. The opening for mounting the distribution axle is Ø16 diameter, roughness class N6, which is extended from the front to Ø18, 17.5mm in length from the edge of the opening 1/15 °. A transition cone of 1.8 / 45 ° was made between diameters Ø16 and Ø18. The other side of the aperture is 1.8 / 15 °.

There are also openings for the inlet and outlet of the working fluid.

3. STARTING AND CHOOSING THE ROBOT SYSTEM IN THE ROBOTSTUDIO PACKAGE

The simulation was created in the software package RobotStudio by ABB (RS), version 5.15.02, whose robot is also used. After starting the program, select *Create new station* and then the *Empty station project* (Figure 5).

Figure 5. Creating of new project

According to the task that the robot should do, we select the desired robot for assembly. In our case, it will be an IRB 140 robot from a series of small industrial robots. RBI 140 has a payload of 6 kilograms. It is intended primarily for jobs: assembly, packaging, cleaning, material handling, etc. (Figure 6).

Figure 6. ABB industrial robot IRB 140

When introducing a robot into the technological assembly system, a number of technical and technological criteria should be considered. Attention must be paid to the workspace of the robot as defined by the manufacturer [3] (Figure 9).

Figure 7. ABB IRB 140 Robot workspace

In order to introduce the robot model into the workspace, in the RS software package, it is necessary to use the ABB library option and select the robot IRB 140. After that, it is necessary to enter into the program the robot stand and work table on which the assembly process takes place. In RS, we use the *Import Geometry* option to import table models converted to the appropriate format (.SAT). Imported models are positioned relative to the robot coordinate system (Figure 8; Figure 9).

Figure 8. Positioning of imported geometry

Figure 9. Positioned tables in the workspace

After positioning in the workspace, which is important to know exactly where the object is located, we place the robotic arm IRB 140 on the first workbench with the *Set position* option (Figure 10) [5].

Figure 10. Positioning the robot on work table

It is also necessary to place the components to be mounted on the second table (Figure 1). When setting up the robot and deciding on the position of the working model, it is necessary to take into account the maximum range of the robot (IRB140 has a maximum range of 810mm), so this robot can perform the assembly process. The robotic arm has the ability to attach various mounting tools. It is important to pay attention to the tool center point TCP ie. its coordinate system. At this point, the robot has a receptacle where the mounting tools are placed [4] (Figure 11).

Figure 11. TCP and tool port

4. APPLICATION OF THE ROBOT STUDIO PROGRAM PACKAGE FOR DETERMINING THE ROBOT PATH

To be able to "drive" a robot along the desired assembly path, we must "teach" it where those paths are. Assembly technology should be considered to make the robot path easier to assemble during assembly. The main RS option for generating a robotic arm path is *Path, AutoPath*. It is located in the *Home* window in RobotStudio (Fig. 12).

Figure 12. AutoPath tool for generating path

After marking all the desired mounting paths, it is the turn to set the basic orientation of the PKI mounting tool. We have designated this position to be in line with the robot's central tool point. This was done by marking the position i.e. target number 10 (*Target 10*), and using the *Modify Target* tool, *Set rotation*, determine the position of the assembly tool (Figure 13).

Figure 13. Setting the basic position of the tool

After setting the position as in Figure 13, right-click on the same target (*target*) and select *Copy Orientation* from the drop-down menu. The next step is to highlight all the targets in the drop down menu of our workobject and right click to open the drop down menu and apply the same orientation to the entire set (*Apply orientation*). After the correct basic orientation, the necessary step is to re-mark all the positions of the targeting tool and use the option to check the availability of all the positions (*Reachability*). We see the check in Figure 14.

Figure 14. Checking the availability of movement positions

With the availability of all positions of the robotic arm, we begin with the configuration of the path of the robotic arm according to the selected path. We will do this by marking the path of the robotic arm from the *Path tools* category, selecting the *Auto Configuration* tool (Figure 15). After selecting the robot path configuration, we can again use the *Auto Configuration* tool to see a simulation of the robot movement along a given path.

Figure 17. Configuring robot arm movements

The process is repeated for each path. Checking available movement and possible errors in movement. There is a possibility that the robotic arm, using linear motion, cannot reach the desired position. Then the first option is to define the movement as a joint (*MoveJ; move joint*). This is done by selecting the movement within the problematic route (*Move; Path*), and using the *Modify instructions* option to change the motion type (*Motion type*) from linear to joint (*linear; joint*), (Figure 18). In the presented *Modify Instructions* option, it is also possible to change the speed of the robot arm.

Figure 18. Option to change instructions

5. MAKING A SIMULATION OF THE INSTALLATION PROCESS IN THE ROBOTSTUDIO PACKAGE

After creating the path, it is necessary to perform a simulation of the given assembly. First we need to select the robotic system we will use, in our case it is RBI 140. We do this by selecting the *Robot System* option under the *Home* part of the RS and setting up the system for our robotic arm selection. The next step is to synchronize with a virtual controller in RS. In the program under the part *RAPID*, we use the option *Synchronize to VC*, ticking all the options, start synchronization (Figure 19)

Figure 19. Virtual controller synchronization

After the synchronization has been completed, it is necessary to set the assembly order according to the set paths. We do this under a part of the RS program called *Simulation*. Select the *Simulation setup* option. In the newly opened window, from the part of *Available Procedures for assembly*, we move the routes to the main sequence of the robotic arm (*Main Sequence T_ROB1*). By selecting *Active Tasks*, marking our previously created robotic system, it is possible to choose to execute the main sequence continuously or for only one cycle (Figure 20).

Figure 20. Main Simulation Sequence

After choosing the routes to execute the main sequence of the IRB 140 robotic arm, all that remains is to start the assembly simulation process with a simple Play command from the simulation part of the RS program. The robotic arm mounts on the specified paths, with minimal error, high precision and high speed.

6. CONCLUSION

The use of a robotic system in the assembly process significantly shortens the assembly time and increases the productivity of the company. It is necessary to analyze the assembly technology of the product itself in order for the robot to complete the assembly process in the shortest possible way and in the best way. The programming of the robot itself is very simple with graphical support in the form of images that simply describe what needs to be entered into the robot simulator, after which the code for controlling the robot's operation is generated.

This paper gives the assembly process of a single subassembly unit, but this robot programming process can be applied to mount the entire hand pump. Two robots can be programmed to operate simultaneously.

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