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CRITERIA FOR IMPLANTS CLASSIFICATION FOR COATING IMPLANTS USING PLASMA SPRAYING BY ROBOTIC COMPLEX

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Abstract The article is devoted to exploring topological-geometrical characteristics of implants, used as prostheses to replace absent or damaged human organs. The criteria for classifying such implants according to physical dimensions, the type of prosthetics of various organs, manufacturing materials and manufacturing companies, etc., are suggested. The problem of applying biocompatible coatings to implants using robotic complex based on an industrial robot from Kawasaki is considered.

For the coating application, the technology of plasma spraying and the corresponding equipment of robotic complex are described. As a result of the carried out studies implants have been selected for subsequent plasma spraying which correspond to possibilities of MPN-004 plasma deposition installation to maintain biocompatible coating of these implants.

Key words: implant, classification of implants, plasma spraying, robotic plasma deposition plants.

AMS Mathematics Subject Classification: 68U35

1 Introduction

Improving the methods of implant systems construction by using modern production solutions is an actual and important problem.

The equipment and complexes for plasma spraying of implants with the integration of industrial robots into sputtering processes allow us to reach a new level of production, to achieve a significant improvement of the implant surfaces characteristics by forming coatings with special properties on the working surfaces [1, 2, 3, 4, 5].

Robotic processes of plasma spraying can significantly increase labor productivity, optimize processing technologies and reduce the production cycle. Robots for plasma spraying and software allow the applying of functional coatings with an accuracy of several micrometers, which let significantly reduce the consumption of materials, perform manipulations, display technological parameters and control them during the deposition process.

Robotic complexes for plasma spraying allow providing a cycle of processing with high efficiency and accuracy, besides, they also permit to avoid interruptions and manufacturing mistakes to be common in manual process.

Research and development of implants that are to replace damaged human organs, followed by spraying of biocompatible coatings using robotic complexes, is an important scientific and technical problem which needs new methods and approaches to solve it.

The purpose of this article is to classify implants according to various criteria for the subsequent development of an effective control system for robotic complex.

2 Object of research

Object of research is implants, used as prostheses to replace completely or part of damaged human organs.

Due to the fact that implants come into contact with other human organs, there is a problem of compatibility of implant and living tissue, which is solved by coating the implants with biocompatible materials.

3 Implant classification criteria

In accordance with the skeletal and physiological structure of a man [6] we will investigate the main types of implants depending on the human organs to which these implants are applied.

For this purpose, we will classify implants according to the criterion of replacement or implantation of various human organs [6, 8, 10, 11]:

- Dental implant;
- Auditory (cochlear) implant;
- Stem-brain implant;
- Heart valves implant;
- Retina implant;
- Extremities implants

Analysis of geometrical-topological characteristics of these implants reveals complexity of their surfaces and it is necessary to use precise equipment, in particular, robotic complexes for the preparation and processing them.

It should be noted that implants are selected for each person separately, so the physical dimensions of implants are parametric functions, which makes it possible to produce an implant by fitting parameters to specific dimensions. As a result of the investigations, the main types of implants have been analyzed by the criterion of their physical geometrical dimensions. Records of these studies are presented in the form of a database, part of which is given Table 1.

Analysis of physical dimensions of implants, presented in Table 2 shows that some implants, particularly dental implants, cochlear implants, retinal and heart valves ones have small size (millimeters and even hundredths of millimeter). It is necessary to develop special device for solving the problem of spraying on such products as the use of industrial robots is not suitable for these purposes.

In addition to classification by type of implants and their geometrical dimensions, it is important to classify them by manufacturing material criterion.

In the research we will analyze implants from titanium, because this metal is the most suitable for creation of implants. Brand of implant manufacture is quite important in the process of their practical application. Information on the used material and implant manufacturers have been collected in the form of a database, some of which are given in Table 2.

Table 1: Database "<Implants">

N	Type of implant	Physical dimensions(mm)	Material	Company manufacturer
1	Dental implants	length -10 Diameter 2 - 6	Titanium	Nobel Biocare, Straumann, Astra Tech, Ankylos, Xive Friadent, AlphaBio, Ards, MIS, Implantium
2	Cochlear implant	Diameter 1- 4	Titanium	Cochlear, Clarion CII Bionic Ear, HiRes 90k, Nucleus 24 Contour, Med-El Combi 40+
3	Heart valve implant	Diameter - 16- 33	Titanium	Edwards Lifesciences, Labcor Laboratorios Ltda, MEDTRONIC, St.Jude Medical
4	Implant of retina	length 0,02	Titanium	LABTICIAN, Pixium Vision, Retina Implant, Argus II, eSight.
5	Implant of the hip joint	Length 15 - 25	Titanium	AESCULAP AG , ESI, SL-Plus, Sulfix-60, Palacos, Cemex, Simplex, Bioosteo, Osteobond, CMW, Zimmer, Lima, Metabloc, CLS, Zweymuller, ISKO, Sinko, ESI, Aesculap
6	Knee Joint Implants	Length arc 50 - 70 Width 30 - 50 Length 20 - 30	Titanium	Zimmer, DePuy, "<Altimed">, Stryker, Smith& Nephew, Lima
7	Implant of elbow joint	Diameter 10-16 length 50 - 280	Titanium	Zimmer , Endoservis, OppO, Medi, Push.
8	Implant of ankle	Length 30- 50 Width 30 - 50	Titanium	ArtusMed, OttoBock, Orlett, PћCЂCЂPћ
9	Neck Diaphyseal Implant	Diameter 12 , length 150, 200, 300, 400 Clip with bone screw- Diameter 6 , length 160 - 200	Titanium	Zimmer, HIPREPLACEMENT, OHST, Streicer - Howmedica, Keramed
10	Implant of the wrist joint	Head size 16	Titanium	Orlett, Ortex, Immobil, Otto Boc
11	Implant joints brush	Interphalangeal joint of fingers Length from 30 to 70 Metacarpal phalangeal joint of fingers Length from 80 to 12 0	Titanium	Zimmer , OppO, Medi, Push.
12	Implant of foot joints	With a rectangle length of 3.4, its height is 3.4 and Width is 4.2, the length of the proximal stem is 11, the length of the distal stem is 6, and the diameter of the stems is 2.2	Titanium	Zimmer Trilogy, DePuy
13	Vertebral implant	Diameter of the rings is 16 when the defect of two vertebral bodies is replaced by 1.8 x 1.4 and Diameter of rings is 16 when the defect of three vertebral bodies is replaced	Titanium	Sulfix-60, Palacos, Cemex, Simplex, Bioosteo
14	Implants of the cartilaginous part of the nose	Length 10- 30	Titanium	Zimmer Trilogy, DePuy

4 Plasma Spraying Technology

Production of metal implants comprises of implant manufacturing stage and the stage of processing its surface. Surface treatment is an important final step in determining the biotolerance of implants.

Implants of titanium and cobalt-chromium composition are made by casting, milling and turning, powder metallurgy, hot stamping as well as electrochemical machining and stamping with subsequent milling. The technological process of plasma spraying in the general case consists of preliminary surface cleaning, activation treatment and direct coating deposition by moving an item with respect to the plasma torch or vice versa. There are some technical characteristics of the process: speed of movement is 2-30 mm/s, the distance between plasma torch and product is 100-150 mm, diameter of the spraying spot is 10-25 mm, coating thickness is 0.05-1.0 mm.

The temperature of heating of parts during plasma spraying does not exceed 100-150°PЎ. The angle between the axis of the particle flow and the surface to be reconstructed should approach 90°PЎ.

Argon or air is plasma gas where the flow rate of argon is 15-20 l/min. Various materials and alloys, refractory compounds, oxides, polymers and their compositions with a particle size of up to 100 μm are used as the powder coating forming material.

Surfacing powder materials are expensive and should be used sparingly. Reduction of powder losses by 10% allows decreasing the cost of 1-2 m. of coating by 2 or more times. Applying a coating thicker than required is considered to be an obvious waste.

As soon as thickness of coating increases, the value of residual tensile stresses will go up, thus there is a danger of destruction of the layer. It is always recommended to get a coating of minimum thickness. Minimum thickness of coating includes allowance for possible wear and for processing after spraying. It is not unnecessarily go deeper into metal when grooving worn surfaces. Optimum thickness of the allowance is 0.15 mm, and for carbide coatings less than 0.1 mm. Minimum thickness of coating after melting may be 0.25 mm.

For coatings of uniform thickness, the grinding allowance is 0.1 to 0.4 mm in radius. Shrinkage at reflow might comprise 20%. For shafts in the areas of press-in, it is necessary to spray coatings with a thickness of 0.13 mm regardless of diameter.

Coating should be continuous, uniform in color, without particles of unmelted metal, without cracks and peeling (blisters). Surface roughness is expected to be not more than 80-100 μm. Coating should be firmly adhered to the base metal and not flake off when tested by the method of applying a grid of scratches. Porosity of coating is not to be more than 20%.

Technological modes of plasma spraying are determined by the type and dispersion of material, the current of the plasma jet and its voltage, the type and flow rate of plasma-forming gas, the diameter of the nozzle of plasma torch, and the distance from the nozzle to the deposited surface [3, 5, 9].

Here are some technologies used in plasma spraying are to be presented. PVD (Physical Vapor Deposition) technology is the physical deposition of titanium vapor onto the surface of a product. High accuracy of coating thickness, exceptional hardness, and average temperature range (400-600°PЎ) means that these coatings can be applied to a wide range of materials, exceeding other processes in their niche.

The product to which PVD coatings are applied is first to be cleaned. Cleaning process varies depending on the level of surface quality, substrate material and geometry. Products are loaded into the vacuum chamber for special devices designed to optimize the load of the camera and ensure uniform coverage.

Vacuum chamber is pumped out to 10-6 mm. Gt; Art. (High vacuum) to remove all contaminants in the system. In the chamber, an inert nitrogen gas is introduced and the voltage is applied to the substrate, resulting in a glow discharge (plasma). This is the cleaning of an item in a glow discharge for the initial stage of metal deposition. Large current and a low arc voltage are applied to the target (solid material used for application).

The metal evaporates and instantly the ions and the basic properties of the evaporation metal remain unchanged throughout the entire metal deposition cycle.

Due to change in the volume of gas, the type of gas during the reactive deposition, structure of coating of ceramics, carbides, nitrides and oxides also transforms.

It should be noted that titanium carbo-nitride is widely used as a coating, which allows prolong tool and implant life expectancy by 2-3 times, since the addition of carbon increases the hardness by 80%.

Thus, plasma spraying systems have been classified according to the criteria that characterize method, type of sputtering, distance to the object, and auxiliary equipment. For practical use of the results obtained, a corresponding database has been created, which also includes information on manufacturers (see Table 3).

5 Robotic complex for plasma spraying

Available equipment available at East Kazakhstan State Technical University named after D. Serikbaev includes industrial robot of Kawasaki RS-010L, with the controller E40F-A001, a compressor with a pressure of up to 6 atmospheres, a plasmatron with a DS120P.33 power supply, a micro plasma deposition unit MPN -004 developed at the Paton Institute, a power source for its firm Fronius Magic Wave 2200 Job G / F and a cooler to it, as well as a milling and engraving machine with a controller RZNC-0501.

Robot is a device consisting of moving parts with six degrees of freedom to move the equipment installed on it to a predetermined profile, it is controlled by means of a programmable controller. The device is installed on the arm of the robot for treating plasma surface and for applying powder coatings in plasma stream in which plasma discharge is generated and stream or powder is fed into a plasma jet in argon atmosphere on substrate of any shape.

The device is designed for plasma spraying of metal and ceramic surfaces of parts and assemblies, which are subject to increased operational requirements for wear resistance, corrosion resistance, as well as for the restoration of worn surfaces. It consists of an inverter power source with gas preparation, a powder feeder and a plasma torch.

Technical characteristics of the plasma installation are the power of the plasma torch is 2 kW, the spraying efficiency is 2-3 kg/h, the operating current of the plasma torch is 60A and the working arc voltage of 30 V.

The following requirements are imposed on biocompatible coatings on implants: coating thickness 300-500 μm, pore size 150 - 300 μm, adhesion strength of coatings to

Table 2: Database "<Physical dimensions of constituent implants">

N	**Type of implant**	**Physical dimensions(mm)**										
		length	**Diameter**	**Width**	**length arc**	**length Clamping**	**Diameter Clamping**	**length Rectangle**	**High**	**length Proximal stem**	**length Distal stem**	**Diameter stem**
1	Dental implants	10	2-6									
2	Cochlear implant		1-4	2								
3	Heart valve implant		16-33									
4	Implant of retina	0.02		0.02								
5	Implant of the hip joint	150-250										
6	Knee Joint Implants	20-30		30-50	50-70							
7	Implant of elbow joint	125	6-14									
8	Implant of ankle	50-280	10-16									
9	Neck Diaphyseal Implant	30-50		30-50								
10	Implant of the wrist joint	150-400	12			160-200	6					
11	Implant joints brush	16										
12	Implant joints of the hand: Interphalangeal joint of the fingers	30-70										
13	Implant joints of the hand: Metacarpopha langeal joint of the fingers	80-120										
14	Implant of foot joints			4.2-5.4				3.4-4.3	3.4-4.2	11-12.2	6-6.4	2.2-2.5
15	Vertebral implant		0.15-0.2									
16	Implants of the cartilaginous part of the nose	10-30										

Table 3: Database "<Plasma Sputtering Plants">

N	Plants name	Method of spraying	Type of spraying	Distance to the object(mm)	Auxiliary equipment	Company manufacturer
1	Alpha	Spray	plasma	300-600	Rotary drive	Alpha Dent
2	FORVAK	Spray	plasma	270	Frequency drive of the valve rotation,-planetary gearing mechanism	Siemens
3	MP-50	Spray	Plasma, high-speed HVOF, gas-flame powder and wire	300	Rotary drive	FLAME SPRAY TECHNOLOGIES
4	PќPќP’-6.6	Point	Vapor deposition of material on a substrate in a vacuum	300	Rotary drive	"<TsVK">
5	TF600	Spray	plasma	300	Frequency drive of the valve rotation,-planetary gearing mechanism	HHV
6	UMPN-02	Point	plasma	300	Rotary drive	Institute of Electric Welding named after EO Paton

the substrate according to ISO 13779-2 - not less than 15 MPa, porosity up to 50%, roughness Ra вЂ“ 150-300 μm.

Parameters of the sputtering process should be as follows: operating current - 16 A; consumption of plasma-forming gas - 140 l/h; distance of spraying - 40 mm; Wire feed speed is 3 m/min, diameter of spraying spot is 5-10 mm [4].

Thus, the created robotic complex allows solving the problem of plasma deposition of implants.

6 Conclusion

Technical characteristics of the robotic complex for plasma spraying allow coat implants with complex topology and surface characteristics.

Due to the use of an industrial robot with the installation of plasma spraying MPN-004, it is necessary that the implants have sufficient physical dimensions. Therefore, for conducting experimental studies, the following implants have been selected:

- Hip replacement implant;
- Knee joint implant;
- Shoulder joint endoprosthesis;
- Elbow joint implant;
- Ankle implant;
- diaphyseal implant;
- wrist joint Implant;
- Interphalangeal implant;
- Metacarpal phalangeal joint implant.

Further investigation will focus on a process control system creation for plasma spraying, constructing trajectories of industrial robot and additional equipment movement for high-quality deposition of biocompatible coatings on proposed implants.

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