机器人弧焊成形系统中离线自动编程

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摘 要：目前的机器人离线编程系统大多采用图形示教方式建立机器人运动路径，然而这种编程方式对于复杂路径来说工作量仍是相当大的，而且对于路径规划直接计算得出的机器人位置数据及弧焊操作指令无法方便地形成机器人程序（relative job，JOB）。文中以弧焊机器人为对象进行了离线自动编程的研究。利用 MOTOMAN 机器人的相对 JOB 数据交换格式，实现了 MOTOMAN 机器人相对 JOB 的离线自动编程，自动生成机器人程序。离线自动编程模块通过 ODBC 接口从弧焊成形系统中相应的规划数据库取得指令代码及数据，充分发挥数据库的优势，有利于离线编程系统的扩展。结果表明，研究的离线编程运行稳定，机器人动作连贯，焊接路径与设计吻合。

关键词：机器人；弧焊成形；离线自动编程；相对 JOB

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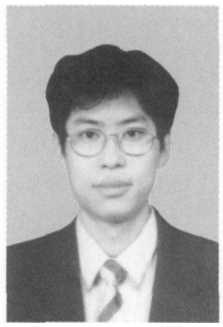

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0 序 言

机器人弧焊成形具有成本低，效率高等优点，其基本原理是对零件进行 3D 建模、路径规划，利用机器人根据所规划的加工路径进行熔焊堆积，实现金属零件直接成形的技术。在电弧成形系统中，堆焊路径的复杂程度较高，使得机器人在线示教方式效率低，无法满足对零件加工灵活、高效的要求。因此，目前对离线编程技术的需求已日益增强[1－4]。MotoSim 是 MOTOMAN 机器人公司提供的基于 Windows 系统的离线编程环境，集成了 MOTOMAN 机器人、变位机及周边辅助设备的图形模型，通过图形示教方式建立机器人运动路径。然而这种图形示教编程方式对于大型工件或复杂路径的编程，工作量仍是相当大的；而且对于路径规划直接计算得出的机器人位置数据及弧焊操作指令无法方便地形成机器人 JOB 程序。因此，针对目前这种情况，文中以 MOTOMAN 弧焊机器人为对象进行了离线自动编程的研究。

1 离线自动编程及弧焊成形系统

以 MOTOMAN 弧焊机器人、Fronius 数字焊机为主要设备建立机器人弧焊成形系统。主要包括 3D 图形建模、焊接路径规划、工艺参数规划、规划数据库及离线自动编程等模块，如图 1 所示。其中，规划进程将焊接路径、焊接速度等工艺参数以一定的数据格式存储于规划数据库。离线自动编程模块通过 ODBC 接口从相应的规划数据库中取得指令代码及数据，并对指令代码进行译码，利用 MOTOMAN 机器人的相对 JOB 数据交换格式，自动生成机器人能够识别的机器人程序。离线自动编程是虚拟规划数据向实际机器人操作指令转换的关键环节。

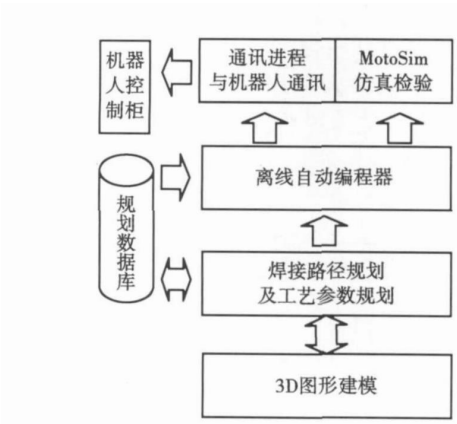

图 1 机器人弧焊成形系统

Fig. 1 Arc prototype system based on arc welding robot

2 相对 JOB 数据交换格式

相对 JOB 是 MOTOMAN 机器人能够识别的一种程序文件格式，可作为离线示教系统与机器人之间

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数据交换的一种界面。通过数据传送所得到的相对JOB为一个*.JBI文件。JBI文件为ASCII编码,以文本方式编辑,一般地具有如下格式

```
/JOB
//NAME＜JOB NAME＞
//POS
///NPOS ＜C＞,＜BC＞,＜EC＞,＜P＞,＜BP＞,＜EX＞
///USER＜N＞
///TOOL＜N＞
///POSTYPE＜T＞
///RECTAN
///RCONF ＜l＞,＜m＞,＜o＞,＜p＞,＜q＞
C**** =X, Y, Z, Rx, Ry, Rz
BC**** =X0, Y0, Z0
EC**** =1, 2
…
//INST
///DATE＜YYYY＞/＜MM＞/＜DD＞＜HH＞:＜TT＞
///COMM ＜COMMENT LINE＞
///ATTR ＜ATTRIBUTE 1＞, …
///FRAME＜C＞
///GROUP1 ＜m1＞,＜m2＞,＜m3＞
///GROUP2 ＜m1＞,＜m2＞,＜m3＞
NOP
MOVJ C**** BC**** EC**** VJ=***.*
…
END
```

JBI文件中,以斜杠(/)开头的指令是伪指令,用来标识数据属性及程序功能结构,如图2所示。其中/JOB表示文件开始,以下包含三部分内容并分别以双斜杠(//)表示伪指令级别://NAME,//POS,//INST。

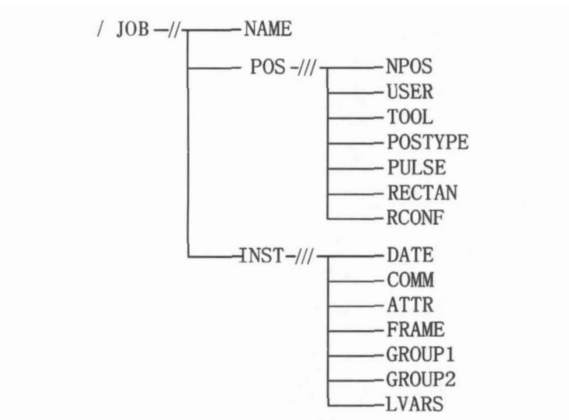


图2 JBI文件中的伪指令

Fig. 2 Pseudo instructions of JBI files

NAME指令记录相对JOB的名字,与该JBI文件名相同。

POS指令标识出机器人位置数据区,记录机器人的位置数据信息。其中,NPOS记录位置数据点的个数;USER记录当前选择的用户坐标系代号;TOOL记录当前选择的工具代号;POSTYPE记录位置数据类型;PULSE标识脉冲数据类型;RECTAN标识直角坐标系数据类型;RCONF记录机器人自身的放置姿态信息。

INST指令标识出机器人指令区,记录机器人的指令数据及属性信息。其中,DATE记录文件的生成时间;COMM记录相对JOB的简要说明;ATTR记录相对JOB的属性;FRAME记录示教坐标系;GROUP1记录第一个移动控制组的构成信息;GROUP2记录第二个移动控制组的构成信息;LVARS记录本地变量个数。

3 离线自动编程的实现

机器人弧焊成形系统中,焊接路径、焊接速度等工艺参数存储于规划数据库。主要包括Command,POS,INST,C_Point,BC_Point,EC_Point,P_Point,BP_Point,EX_Point等表格。其中,Command表格记录机器人操作及焊接指令编码;表格POS,INST记录JBI文件的相关伪指令信息;其余6个表格则用于记录由规划功能模块计算所得的弧焊机器人、基座、变位机的一系列位置数据及变量。

在VC++环境下,根据MOTOMAN机器人JBI文件结构,在自动编程软件中建立相应的C++类与数据库中相应信息对应,主要包括CCommand,CPos,CInst,CCPoint,CBCPoint,CECPoint,CPPoint,CBPPoint,CEXPoint等。通过ODBC接口从相应的规划数据库中查寻指令代码及数据,并对指令代码进行译码,转换成机器人识别的ASCII码JBI文件。自动编程成功后,JBI文件显示在离线自动编程软件的用户面上,如图3所示。

在程序主界面的自动编程按钮上添加消息响应函数OnAutoProgram()。对于CCPoint等包含多行数据信息的类,通过SQL方式进行相关数据信息的查询。

自动编程功能的部分程序源代码如下所示

```
void CMotoManDlg::OnAutoProgram()
{
    CString string[10000];
    CString tag;
    int RowNum=0;
```

```
string[ RowNum] =”/JOB”;
string[ ++RowNum] =”//NAME ”;
const CString DouHao=”, ”;
const CString equal=”=”;
if ( ! pos—> IsBOF())
    pos—> MoveFirst();
……
```

图 3　离线自动编程软件用户界面

Fig. 3　User interface of offline automatic programmer

4　试验验证

在MOTOMAN HP6/NX100 机器人弧焊成形系统中，结合实际机器人焊接过程中常用指令设计了焊接试验，以验证离线自动编程结果的正确性。试验焊缝中包括直线插补方式、圆弧插补方式、与变位机协同直线插补方式、与变位机协同圆弧插补焊接方式四种常见机器人运动形式，同时具有相应的弧焊操作指令，试验焊缝如图 4 所示。将焊接试验过程中机器人的各位置点数据信息按约定格式存入数据库文件中，通过离线自动编程将其转换成 JBI 文件。

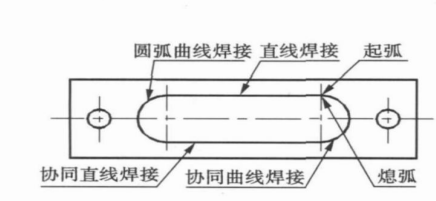


图 4　试验焊缝设计

Fig. 4　Experiment weld design

在 MotoSim 环境下，对自动生成的 JBI 文件进行离线仿真，在虚拟环境下验证该机器人相对 JOB 的正确性，保证了机器人在线试验的运行安全。仿真试验的机器人设备及焊接结果如图 5 所示。

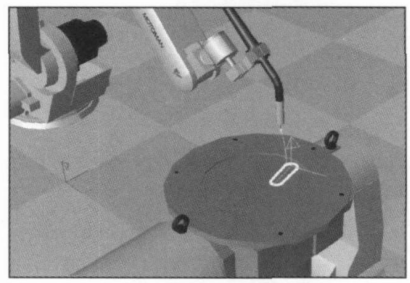
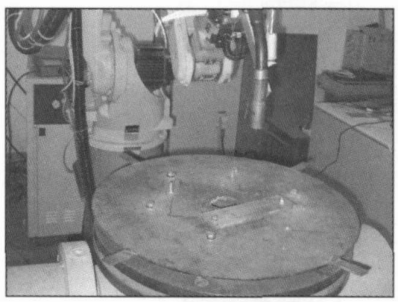


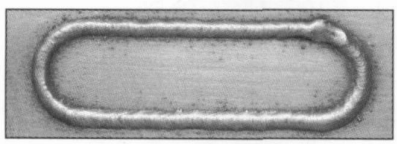
图 5　仿真试验及焊枪轨迹

Fig. 5　Simulated experiment and track of welding torch

MotoCom32 是 MOTOMAN 公司提供的机器人通讯 API 接口。通过该接口将经仿真验证后的 JBI 文件传输到 HP6 机器人的控制柜 NX100 中，进行在线的机器人焊接试验。在线试验的机器人设备及完成的焊缝如图 6 所示。仿真及在线弧焊试验表明，离线自动编程生成的机器人程序运行稳定，焊缝成形美观，机器人动作连贯，焊接路径与设计吻合。



(a) HP6/NX100弧焊机器人



(b) 完成的焊缝

图 6　在线试验的机器人设备及完成的焊缝

Fig. 6　Robot equipments and finished weld of online experiment

5　结　　论

（1）根据机器人弧焊成形系统中路径规划所得的机器人位置数据及弧焊操作指令，通过 VC++实现了 MOTOMAN 机器人相对 JOB 的离线自动编程。

（2）离线编程器通过 ODBC 数据接口与规划数据库建立数据连接，可发挥数据库在记录数据方面

的优势,有利于弧焊成形中离线编程系统的扩展。

(3)结合 MOTOMAN 机器人,通过仿真及在线弧焊试验表明,研究的离线编程运行稳定,机器人动作连贯,焊接路径与设计吻合。

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different in the second specimen. One of them is 1 mm, and the other one is 2 mm. Meanwhile, the size of bridge between two hole are different. The former is 0.4 mm, and the later is 0.2 mm. Then the numerical resultes were compared with that of the experiment to verify the validity of Gurson damage models in describing the initiation and propagation of cracks during their evolution. The results show Gurson damage model give good results to the second specimen. Because the stress triaxiality of second specimen greater than 0.4.

Key words: aluminium alloy; double-hole test; damae; finite element method

Wear resistance of chromium carbides coating alloyed by vacaum electron beam LU Binfeng, LU Fenggui, TANG Xinhua, YAO Shun (Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai Jiaotong University, Shanghai 200240, China). p77—80

Abstract: Fe/Cr/C powder mixtures were employed to modify the surface of a low carbon steel substrate by electron beam irradiation in vacuum condition. By optimizing the electron beam parameters, chromium carbide is in situ synthesized in the surface composite layer. The surface composite layer was analyzed with optical microscope, XRD analysis and trobological test. There are two main phases in the surface composite layer: chromium carbides as hard phase and austenite as tough phase. There are little typical hexagonal primary chromium carbides in the surface composite layer. Eutectic chromium carbides dispersively distribute between the interface of austenite phase to form a net like structure. It is metallurgical combination in the surface composite layer and the substrate. The existing of carbides in the composite layer provides a notable improvement on the wear resistant property of the surface layer.

Key words: surface composite layer; vacuum electron beam irradiation; chromium carbide; wear resistance

Offline automatic programming of arc prototype system based on arc welding robot DU Naicheng[1,2], HU Shengsun[1,2], DING Wei[1] (1. School of Materials Science and Engineering, Tianjin University, Tianjin 300072, China; 2. Tianjin Key Laboratory of Advanced Joining Technology, Tianjin university, Tianjin 300072, China). p81—84

Abstract: At present, methods of graphic teaching for robot are mostly adopted in offline programming system to establish the path of robotic movement. However, for this programming of the approach complex path, the workload is still a large. Moreover, the robot procedure (JOB) is hardly formed by using the position data and welding instructions, which calculated directly by path planning. The offline automatic programming was researched for arc welding robots. The relative JOB is a data exchange interface of MOTOMAN robots. With this interface, the offline automatic programming module generates robots procedures. Through ODBC interface, offline automatic programming module queries the planning instructions and data in the corresponding database in the arc prototype system. The advantages of database are conducive to the expansion of offline programming system. The experiment results show that the researched offline programming operates stably, and the robot moves coherently, and the welding path is accordant to the design.

Key words: robot; arc prototype; offline automatic programming; relative job

Quantitative analysis method of geometrical precision quality on precision welding structure KONG Liang[1], YU Hailiang[1], JIN Xin[1], WU Yixiong[1,2] (1. School of Materials Science and Engineering, Shanghai Jiatong University, Shanghai 200030, China; 2. Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai Jiaotong University, Shanghai 200240, China). p85—88

Abstract: Based on fussy set theory, a quantitative method for welding geometrical quality control of precision welding structure (PWS) is presented. The "Quality Differentiation Coefficient" which characterizes the relation between quality difference and effective quality essentials is adopted to formulate the qualitative linguistic variables of welding quality difference properties. The welding quality analysis model which could fully utilize experts experiments and historical data for PWS is established to quantificational analysis and decision-making.

Key words: precision welding structure; welding geometrical precision; quantification; quality analysis

Misalignment production and its prediction model in tailored blank laser welding XIN Liming[1,2], ZHAO Mingyang[1], XU Zhigang[1] (1. Shenyang Institute of Automation, Chinese Academy of Science, Shenyang 110016, China; 2. Graduate School of the Chinese Academy of Sciences, Beijing 100039, China). p89—92, 96

Abstract: Misalignment is an important quality evaluation standard in tailor welded blanks. The control of misalignment, especially for thinner blanks, is a difficult problem in tailored blank laser welding process. The production and control of misalignment is studied based on a tailored blank laser welding system. The influential factors of the misalignment are obtained after numbers of experiments: the deformation of the blanks before welding, the intensity of the clamping force, the uniformity of the clamping force, deformation of the clamping beam, flatness error of the based platform and the welding process. A mathematical model is established according to the analysis of misalignment. Experimental results indicate that the model provides an effective theorical guidance in improving welding quality.

Key words: tailored blank laser welding; misalignment; finite element analysis; misalignment prediction modeling

Interfacial structure and properties of galvanized steel sheet joined by pulsed arc brazing process LI Ruifeng, YU Zhishui, HE Jianping (College of Materials Engineering, Shanghai University