# 基于SolidWorks的焊接特征建模系统

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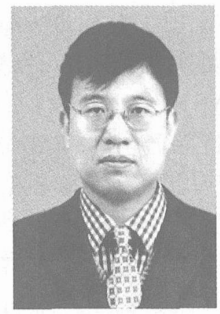

王志江

摘 要：焊接系统的特征建模技术是焊接机器人离线编程领域的一项关键技术，然而现有的“焊接特征建模系统”未能建立焊缝几何模型，使焊接意图不明确，不能有效地提取焊接特征。针对以上问题，在SolidWorks平台之上，采用VC++ 6.0作为二次开发工具，建立了一个焊接特征建模系统，完善了焊缝的几何造型功能，并能有效地提取各种焊接特征，满足了离线编程系统对工件信息的需要。

关键词：焊缝几何造型；焊接特征提取；特征链；特征建模；SolidWorks
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## 0 序 言

20世纪80年代后期，CIMS技术的发展要求传统的造型系统除了满足自身信息的完备性之外，还必须为其它系统（如CAPP、PDM、ERP、CAM等）提供反映设计人员意图的非几何信息，如公差、材料等。而早期的线框几何模型（wireframe model）、表面几何模型（surface model）、实体造型技术（solid model），都是从几何的角度出发，而对于非几何信息，如材料、公差、工艺、成本等，则没有反映，因而实体的信息是不完整的[1]。咱此需求的推动下，出现了特征造型技术。

特征是由一定的几何、拓扑信息与一定的功能和工程语义信息组成的集合，是定义产品模型的基本单元。将特征引入几何造型系统增加了几何实体的工程意义，为各种工程应用提供更丰富的信息，并且在很大程度上促进了CAD/CAPP/CAM系统的集成。

随着基于几何造型的离线编程技术在焊接机器人领域的应用，尤其是自动编程技术和任务级编程技术的研究与应用，不仅要求CAD平台能够对工件进行建模，而且还要能够获取工件的加工信息（如焊缝位姿、形态、板厚、坡口等），以解决与后续模块间的信息交换、共享问题。因此焊接的特征建模技术成为了一个迫切需要解决的技术问题。

文中首先对焊接产品特征建模的特殊性进行阐述；然后介绍本特征建模系统的开发平台SolidWorks；再针对现有焊接特征建模系统的不足，对焊接特征重新进行分类，并提出了特征建模的数据模型及系统模型，构建了一个焊接特征建模系统。

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## 1 焊接特征建模技术

焊接结构是一种机械加工产品，其设计和制造也同样面临与其它机械产品相似的问题。但焊接结构的设计制造也有其特点：（1）焊接工艺较机械加工复杂，规则描述较少，变化较大；（2）焊接结构的自动化生产多采用机器人和变位机等自动化机械；（3）焊接结构多为型材和板材组装；（4）焊接结构装配连接中焊缝位置较为多样。因此，焊接结构的特征建模有其自身特点，不能直接照搬通用机械CAD系统。焊接结构特征建模要满足五点要求：完整表达焊接意图；支持标准；与几何实体相对应；提供正确性检验并设初值；显示焊接符号[2]。遵循CAD技术中对特征的定义，每个焊接特征中不仅要包括具体构造点、边、面等几何信息，还要包括工艺制造信息等非几何信息。

## 2 平台的选择

作者选择SolidWorks作为开发平台，基于多方面考虑。首先，SolidWorks是当今世界基于NT/Windows平台的三维机械设计CAD软件系统的主流产品，价格适中，并且易学、易用，操作过程直观、简单，功能强大，目前已在国内外中小型企业中得到广泛应用；其次，SolidWorks采用了Parasolid建模核心。Parasolid采用边界表示法（B－rep）表示物体，提供较

全面的关于点、边、面的信息。对应此边界表示法，SolidWorks API 开发工具提供了相应的 COM 对象模型，图 1 为 SolidWorks 中边界表示相关的对象模型图，这使得用户可以根据需求，很方便地利用 VB 和 VC ++对其进行二次开发；再次，SolidWorks 是支持特征建模的 CAD 软件平台，用户只需针对焊接的应用，重点研究焊接工件的特征建模实现技术；最后，SolidWorks 是一个开放性的系统，与其它三维设计软件系统具有非常好的兼容性，可以很方便地进行后续的有限元分析和动力学分析及数控加工[3]。

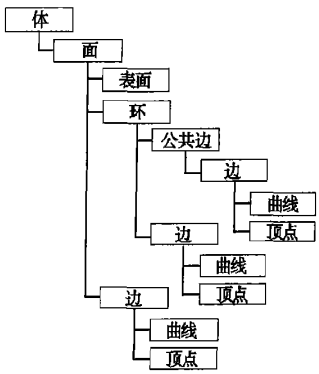



图 1 SolidWorks 中边界表示相关的对象模型图

Fig. 1 Structure of boundary-representation model in SolidWorks

## 3 焊接特征的分类

以熔化极气体保护电弧焊的接头设计为例进行分析，该焊接方法的接头设计中，主要是根据工件厚度，工件材料、焊接位置和熔滴过渡形式等因素来确定坡口形式、底层间隙、钝边高度和有无垫板等工艺信息[4]。工件厚度和工件材料是和焊接工件相关的属性；坡口形式等属于坡口的设计，是接头设计范畴。如果将接头设计看作一种加工，那么焊接工件则为接头设计提供了所需的加工信息。根据上述分析，焊接特征可以划分为板特征和接头特征。同时根据焊接特征的用途是否与焊接接头直接相关，可以将焊接特征划分为内部特征和外部特征。

板特征为接头设计提供加工信息，包括形状、材料、尺寸等与板相关的特征，这些特征与接头的设计息息相关，板特征为内部特征。

接头特征为离线编程系统后续模块提供加工信息，为外部特征。焊接接头特征是具有一定坡口形式和焊缝形状的几何体同其它加工信息属性组成的信息集合，是接头设计的最终结果。接头特征包括形式属性、焊缝属性、坡口属性和装配属性等。图 2 表示了焊接特征建模系统中的特征关系。

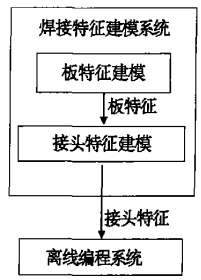



图 2 焊接特征间关系模型

Fig. 2 Relationship of welding features

## 4 焊接特征建模系统的实现

### 4.1 特征建模系统的数据模型

建立系统数据模型一方面要考虑如何对焊接特征进行组织，另一方面还要考虑方便地为离线编程系统后续模块提供信息。SolidWorks 平台是一个支持特征建模的系统，它采用特征历史树对用户建立的特征进行管理，将特征产生的历史过程以“树”的形式记录下来，可以用类似资源管理器的方式完成特征加入、删除、更名、排序以及修改等操作。考虑到唯有接头特征为后续模块提供加工信息，系统数据模型借助 SolidWorks 平台的特征管理功能，仅对接头特征进行了组织。

文献[5,6]采用了二叉树的数据模型，对于表达整个装配体是很恰当的，但是焊接特征建模所关心的并不是如何对装配体进行管理，而是用户定义了哪些焊接接头。因此作者采用了焊接接头特征链的方法，对接头特征进行组织。图 3 表示了焊接接头特征链的结构图。

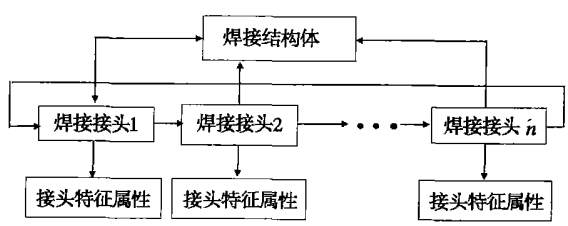



图 3 焊接接头特征链结构图

Fig. 3 List structure of welding features

### 4.2　焊接建模系统的结构

根据焊接接头形成的操作过程以及特征的定义，焊接特征建模系统可分以下几个步骤来实现：系统应首先建立焊接工件（板）的几何模型，并对焊接工件进行初步装配；其次获取板的特征信息（材料、板厚），并根据焊接工件的装配关系，进行焊接接头的设计；然后根据焊接接头特征的定义，进行焊缝建模（包括坡口建模）；最后提取焊缝信息完成接头的特征建模。

焊接特征建模系统建立在 CAD 软件平台之上，所以系统完全可以借助 CAD 软件的优势和功能，完成焊接特征建模所需的部分任务，无需花费大量精力去实现焊接工件的装配变换和装配检查等工作。因此，作者以支持特征建模的 SolidWorks2004 为平台，应用其二次开发工具 SolidWorks API 实现该焊接特征建模系统，其系统结构如图 4 所示。

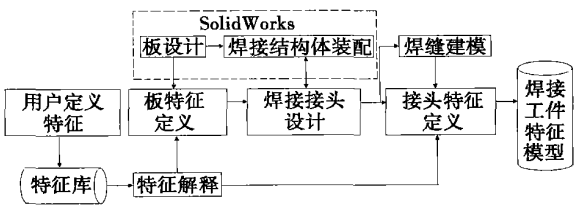



图 4　焊接结构特征建模系统结构

Fig. 4 Framework of feature-based modeling system for welding

对于板的设计由 SolidWorks 软件来完成；且通过设立一定的约束条件，把生成的各种零件（板件）装配起来，实现初步的焊接结构装配。

焊接特征定义模块用于获得焊缝的形状（圆弧或直线）、从用户输入的信息（如用户指定的边、面等）提取焊缝点的位置姿态、坡口形状、尺寸等信息。

特征库中存放各种焊接特征的定义模板（如板特征的内容、接头特征所需定义的参数），工件建模过程中应用到的各种标准等，并提供了接口供用户添加和修改。

### 4.3　焊缝建模及信息提取

对于板的设计及特征提取相对简单，可以由特征识别或交互性特征定义[7] 的方式指定。这里仅对关键技术——焊缝建模和焊缝信息提取加以介绍。

#### 4.3.1　焊缝建模

严格意义上讲，焊接特征建模系统应该包含板的设计，而且还应具有焊缝几何建模功能。本文通过 SolidWorks API 函数，重新开发了适用于焊接特征建模系统的焊缝建模功能，选择了 SolidWorks 支持的 ISO（国际标准化组织）标准，对焊缝进行分类和建模。图 5 为焊缝建模过程中焊缝类型选择对话框，通过焊缝类型选择，相关尺寸定义，结合面选择等几个对话框来完成焊缝的几何造型。焊缝的几何造型形象逼真，接近实际情况，图 6 即为 V 形坡口对接焊缝的几何模型。

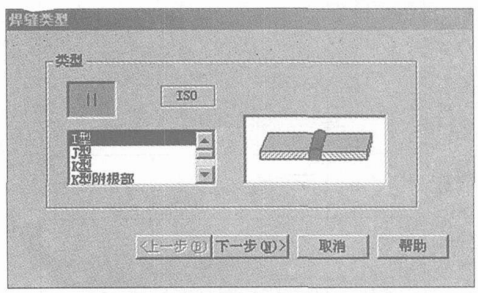



图 5　焊缝类型选择对话框

Fig. 5 Choice dialog of welds types

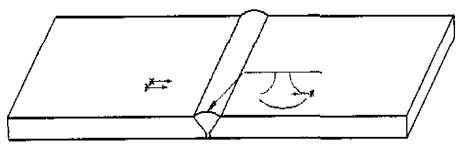


图 6　V 形坡口对接缝几何模型

Fig. 6 Geometric model of Vgroove butt weld

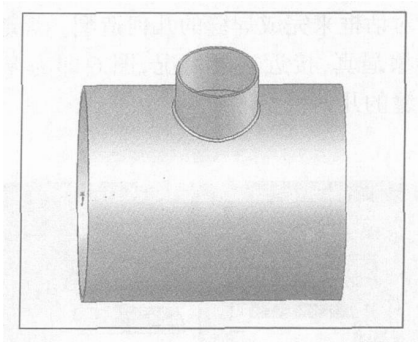
对焊缝进行几何建模具有重要的意义。首先，填补了现有焊接特征建模系统没有焊缝几何体表示的空白；其次，焊缝建模过程中用户输入的信息可以直接或间接的为后续模块提供各种信息；最后，通过焊缝几何模型，可以计算出焊缝的体积和横截面面积，为多道焊计算提供参考。

#### 4.3.2　焊缝信息的提取

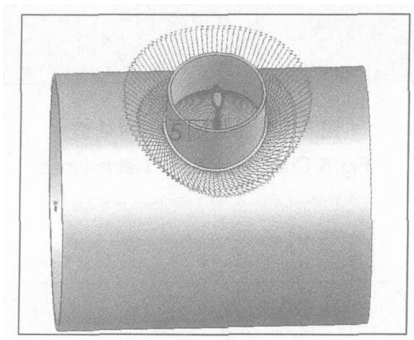
焊缝信息在后续的模块中有着不同的用途，根据其用途的不同，将焊缝信息分为焊接参数规划用属性和路径规划用属性。其中焊接参数规划用属性包括：板厚、接头形式、坡口形状等，属性数目较少，并且数值单一，可采用特征识别或交互式特征定义方式建立；路径规划用属性是指焊缝上关键焊缝点的位置姿态，一般通过几何信息提取的方式获得必要信息，实现比较困难，特别对于形状复杂的焊缝。下面对焊缝点位姿的获取（以角焊缝为例）进行讨论。

角焊缝截面是扇形，一般将焊缝点的坐标原点设置在扇形两边的交点处，定义坐标系的 $x$ 轴方向为焊缝的前进方向，定义坐标系的 $z$ 轴为扇形内两

边夹角的角平分线方向，$y$ 轴由右手定则得到[8]。图7为一条马鞍形焊缝的焊缝点位姿示意图。



(a)马鞍形焊缝



(b)焊缝点位姿

图7 马鞍型焊缝点位姿信息提取

Fig. 7 Position and orientation extraction of saddle-shaped weld

## 5 结 论

(1) 以SoildWorks为平台开发了一个焊接特征建模系统，具有操作简单，功能强大，开放性好等特点。

(2) 根据焊接接头设计要求及离线编程系统的需要，对焊接特征进行了重新分类，采用特征链方法对焊接接头特征进行组织，并给出了焊接特征建模系统的系统结构。

(3) 焊接特征建模系统实现了焊缝的几何造型，有效的提取了焊接特征，为后续焊接无碰路径规划及焊接参数规划提供了丰富的信息。

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linear ones. In the experiment, the maximum error is 2.9 mm and the average error is 1.5 mm when a rather large focal length is used. An analysis of factors influencing the calibration accuracy is done based on the experimental process and results.

**Key words**: virtual environment calibration; human-machine interaction; remote welding

**Welding quality real-time monitoring system for auto-body assembly** XU Jun, LI Yong-bing, CHEN Guan-long (Shanghai Jiaotong University, School of Mechanical and Power Energy Engineering, Shanghai 200030, China). p41—44

**Abstract**: This paper introduces a new auto-body spot weld quality monitoring system using electrode displacement. This system solves the interference problem of sensor mounting by designing special fixture, and can be successfully applied on the portable welding machine. It has capable of making diagnosis of process variations such as surface asperities, shunting, worn electrode and splash with real-time electrode displacement. Through confirmation of application in the workshop, monitoring system has good stability and reliability, and is suited for monitoring welding quality in production.

**Key words**: resistance spot welding; electrode displacement; fault diagnosis; quality monitoring; portable welding machine

**Microstructure and performance of laser cladding Co+ $Cr_3C_2$ composite coating** SI Song-hua, XU Kun, LIU Yue-long, ZHOU Hai-xiang (School of Material Science and Engineering, Anhui University of Technology, Maanshan 243002, Anhui, China). p45—48

**Abstract**: Laser cladding Co-based alloy coating (Co50) and Co-based alloy composite coating (Co+ $Cr_3C_2$) with different $Cr_3C_2$ addition (20%, 40%, 60%, mass fraction) on low carbon steel substrates has been obtained. Microstructure and performance of the coatings have been comparatively discussed in the same test conditions. It is shown that the Co50 coating consisted of many dendritic solid solution γ— Co and eutectic structure (γ— Co and $Cr_{23}C_6$) between the dendrites. The Co+ $Cr_3C_2$ composite coating consisted of un-dissolved $Cr_3C_2$ particles, bacilliform or nubbly rich-chromium carbides ($M_7C_3$) and very finer dendrite structure(γ— Co and $Cr_{23}C_6$) between the carbides. $Cr_3C_2$ particles remodeled the solidification characteristic of the composite coating, and fined the dendrite structure. With the increase of $Cr_3C_2$, $Cr_3C_2$ particles un-dissolved and the rich— chromium carbides were also increased. Surface hardness, wear resistance, high temperature oxidation resistance at 1300℃ and corrosive resistance in 30% vitriol of the composite coatings are obviously better than that of the Co50 coatings. With the increase of $Cr_3C_2$, oxidation resistance and corrosive resistance were increased, but wear resistance of the Co + 40% $Cr_3C_2$ composite coatings was the best. Laser cladding Co + 40% $Cr_3C_2$ composite coating had the best integrative performance.

**Key words**: laser cladding; Co— based alloy; $Cr_3C_2$; microstructure; wear resistance; oxidation resistance; corrosive resistance

**Activating-tungsten inert-gas welding for TA15 titanium alloy** XIONG Liang-tong, ZHOU Zhi-gang, DONG Zhan-gui (Beijing Xinghang Mechanical-Electric Plant, Beijing 100074, China). p49—52

**Abstract**: In the view of weld form, weld pore, joint mechanical properties, microstructur and joint anti-erode performance, etc, A— TIG (activating-tungsten inert-gas) welding for TA15 titanium alloy has been studied. The experimental results show that compared with conventional TIG(tungsten inert-gas) welding, A— TIG welding can increase weld bead penetration while decrease weld bead width, and can decrease the number of pore effectively, also can enhance joint tensile property and bend property. Heat-affected zone of A— TIG welding is narrower, and its microstructure is finer in comparison with TIG welding, while their microstructures of weld zone are almost same. The activating flux doesn't affect joint anti-erode performance. A— TIG welding is superior to conventional TIG welding for TA15 titanium alloy.

**Key words**: TA15 titanium alloy; activating-tungsten inert-gas welding; property

**Calibration of scanning circular laser and seam detecting** LU Jian-bo, XU Pei-quan, YAO Sun, TANG Xin-hua (Welding Engineering Institute, Shanghai Jiaotong University, Shanghai 200030, China). p53— 56

**Abstract**: A new scanning circular laser vision sensor is designed. When the laser is projected on the weld, a light circularity is formed. The principle of 3D measure is stated, and camera calibration and structural light calibration are done. The parameters of camera and equation of structural light under camera reference frame are gained. The pictures of various welds under structural light are collected. By the characteristic of weld after image processing, welds can be identified and the coordinates of characteristic spot can be obtained.

**Key words**: circular scanning laser; calibration; seam detecting

**Feature-based modeling system for welding on SolidWorks platform** WANG Zhi-jiang, HE Guang— zhong, GAO Hong-ming, WU Lin (National Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China). p57— 60

**Abstract**: Feature-based modeling is a significant technology in the robotic welding off-line programming. However, there is not a geometric model of weld in the previous feature-based modeling systems for welding. It makes the welding intention vague and the feature extractions of welding difficult. The feature-based modeling system was established by redevelopment of Solidworks with VC++ 6.0. The geometric model of weld was set up and it made feature ex-

tractions of welding easier. In addition, the feature-based modeling system provides the robotic welding off-line programming system with adequate information and is successfully applied.

**Key words**: geometric model of weld; feature extraction of welding; list structure of features; feature-based modeling; SolidWorks

**Melting characteristic of twin electrode single arc welding II. Self-regulating effect of arc on two cores melting** HAN Bin[1], ZOU Zeng-da[2], QU Shi-yao[2] (1. School of Mechanical and Electronic Engineering, Petroleum University of China, Dongying 257061, Shandong, China; 2. School of Materials Science and Engineering, Shandong University, Jinan 250061, China). p61—63, 80

**Abstract**: Two cores melting speed can keep consistence is very important for twin electrode single arc welding to be stabilized. The melting consistency of two cores is influenced by electrode type, welding current etc. The sufficient condition of two cores melting coincidence is the effective anode drop equal to the effective cathode drop, the more the difference of two values the more the melting inconsistent degree. The arc has a self-regulating effect on melting of two cores, that is, during the arc burning, even if the ends of two cores have different length in the arc, two cores can keep uniformly melting speed, and the arc can stably burn. The principle of the self-regulating effect is that different heat production of cathode and anode make two cores length in the arc different. The longer weld core stretching into the arc column gets more heat from the arc column to accelerate its melting. In general, the self-regulation effect of arc increases with the reducing of two-core span and increasing of welding current.

**Key words**: twin electrode; single arc welding; two cores melting; self-regulation effect

**Submerged arc welding wire matched with X80 pipeline steel** ZHANG Min, YAO Cheng-wu, FU Chong, LV Zhen-lin (School of Material Science and Engineering, Xi'an University of Technology, Xi'an 710048, China). p64—68

**Abstract**: By analyzing the influence of the microstructure for weld deposited metal of high strength low-alloy steel on mechanical properties, the compound microstructure deposit with mainly the acicular ferrite (AF) and a small quantity of the granular bainite (GB) was applied to the welding wire for X80 pipeline steel. Based on the driving force concept of microstructure transformation, and combined with the acicular ferrite nucleated mechanism at nonmetallic inclusions and microalloy toughness theory, the Mn—Ni—Mo—Ti—B alloy was selected to study the welding wire of X80 pipeline steel. The results of experiments show that the weld deposited metal will fulfil the demands of strength and toughness and low-temperature toughness by choosing and controlling alloy elements rationally, and the developed 1# welding wire can be used for X80 pipeline steel.

**Key words**: X80 pipeline steel; submerged arc welding; low temperature toughness; acicular ferrite; inclusion

**Effect of $TiO_2$ on detachability of stainless steel electrode** LI Ping, MENG Gong-ge (Harbin University of Science & Technology, Harbin 150080, China). p69—72

**Abstract**: With uniform design method, tooking the coating ingredients as independent variables and slag detachability as the target function in the formula and usability test, the effects of coating components on the detachability of stainless steel electrode were studied. Based on the calculates and analysis result, the two bigger effective supplementary materials-rutile and the powder of $TiO_2$ were studied. When they (mainly $TiO_2$) increase, the microscopic structure in the slag will form branchlike or the stronger directive frame-like structure. The white fir-tree crystal phase gets more and the detachability turns better, as the branches get longer, the branching area bigger and denser.

**Key words**: uniform design; mechanism; detachability; microstructure

**3D finite element simulation on stress-strain distributions in all position root butt welding of pip** HUANG Si-luo[1,2], XUE Yong[1], ZHANG Jian-xun[1], Chen Zong-qiang[2] (1. Xi'an Jiaotong University, Xi'an 710049, China; 2. Maoming Petrochemical Machinery Plant, Maoming 525024, Guangdong, China). p73—76, 84

**Abstract**: Based on thermal—elastic—plastic theory, a 3—D finite element model of root butt welding of SA335 P91 steel pipe was carried out with ANSYS software. Using moving heat source, the transient temperature field and welding stress-strain field in root butt welded joint of a pipe were analyzed. Moreover, the distributions of axial and hoop transient stresses to close the two-half seam joint were investigated. The calculation results show that the axial and hoop stresses at the keyhole center are tensile, specially, the edge stress effect is remarkable where the hoop stresses are stronger than the axial ones, and how the holding time of heat source in the keyhole and the welding current influences the distribution of stresses and strain during the high temperature solidification is also discussed.

**Key words**: SA335 P91 steel pipe; numerical simulation; stress-strain field; solification cracking

**Evaluation of welding procedure specification with crack tip opening displacement in steel box beam** MIAO Zhang-mu[1], WU Wei-guo[1], TAO De-xin[2], XIE Zhi-hua[3] (1. School of Transportation, Wuhan University of Technology, Wuhan 430063 China; 2. School of Logistics, Wuhan University of Technology, Wuhan 430063 China; 3. The Seventh Engineering Company Ltd., Of China Railway Major Bridge Bureau, Jiujiang 332004, Jiangxi, China). p77—80

**Abstract**: The limitations and problems of evaluation of welding procedure specification (WPS) of steel box beam with impact test were analyzed. It is necessary to use the crack tip opening displacement (CTOD) test to evaluate WPS of steel box beam. The CTOD