MECH 572 Introduction to Robotics

Midterm Exam **October 30, 2008, 2:30–4:00**

N.B.: Figures cited in this examination sheet are to be found in the textbook.

1. (25%) Find the angle and the direction of the axis of rotation of the matrix $\mathbf{Q}$ that takes frame $\mathcal{F}(O, X, Y, Z)$ into frame $\mathcal{F}'(C, X', Y', Z')$ of Fig. 2.13. *Hint: Define unit vectors* $\mathbf{i}'$, $\mathbf{j}'$ *and* $\mathbf{k}'$ *parallel to* X', Y' *and* Z'*; then, notice that expressions for* $\mathbf{i}'$ *and* $\mathbf{k}'$ *in terms of* $\mathbf{i}$, $\mathbf{j}$ *and* $\mathbf{k}$ *are straightforward. An expression for* $\mathbf{j}'$ *can be obtained as a cross product of known vectors. As well, convert all your square roots and fractions to decimal form at the outset, using four digits.*

2. With reference to Fig. 3.9, a force $\mathbf{f}_1$ of 10 N acts on the cube $AB \ldots H$ along edge EH, directed from E to H. A second force $\mathbf{f}_2$ of 10 N as well acts along edge CG, directed from C to G.

   (a) (10%) Find the wrench acting on the cube if the moment is taken with respect to the *centroid*[1] M of the cube, of position vector $\mathbf{m}$, in terms of the side length a of the cube.

   (b) (15%) Find the Plücker coordinates of the wrench axis in frame A, X, Y, Z.

3. A wrench $\mathbf{w}$ acting on the EE of a six-revolute robot is measured both by joint-torque sensors that measure the torque exerted by each motor when balancing $\mathbf{w}$ statically and by a six-axis sensor collocated on the gripper. Upon processing the joint torques $\{\tau_i\}_1^6$, a wrench value $[\mathbf{w}]_1$ is obtained, and compared with the wrench value reported by the gripper wrench sensor $[\mathbf{w}]_6$, in EE coordinates. The two numerical values are displayed below:

$$[\mathbf{w}]_1 = [1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1]^T, \quad [\mathbf{w}]_6 = [0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0]^T$$

   (a) (10%) List the conditions that the two wrench values must satisfy in order for them to be acceptable, and show that the two measurements satisfy these conditions.

   (a) (15%) Find the matrix $\mathbf{Q}$ that describes the orientation of the EE, i.e., the matrix that carries $\mathcal{F}_1$ into $\mathcal{F}_6$.

4. (25%) Attached is the data sheet of the Fanuc S-700 robot. Based on this sheet, produce a table of Denavit-Hartenberg parameters that describe the geometry of the robot. In the figures, all dimensions are indicated in mm. In order to speed up the marking, **use the $-$ and $+$ signs associated with the joints to define the Z_i-axes unambiguously.**

[1] The centroid of a geometric solid is the centre of mass of the same solid if it is considered as an object of uniform mass distribution.

後方へのサービスもできる新世代の中形多目的ロボット
New generation middle class multipurpose robot servicable to the backside

FANUC ROBOT S-MODEL 700

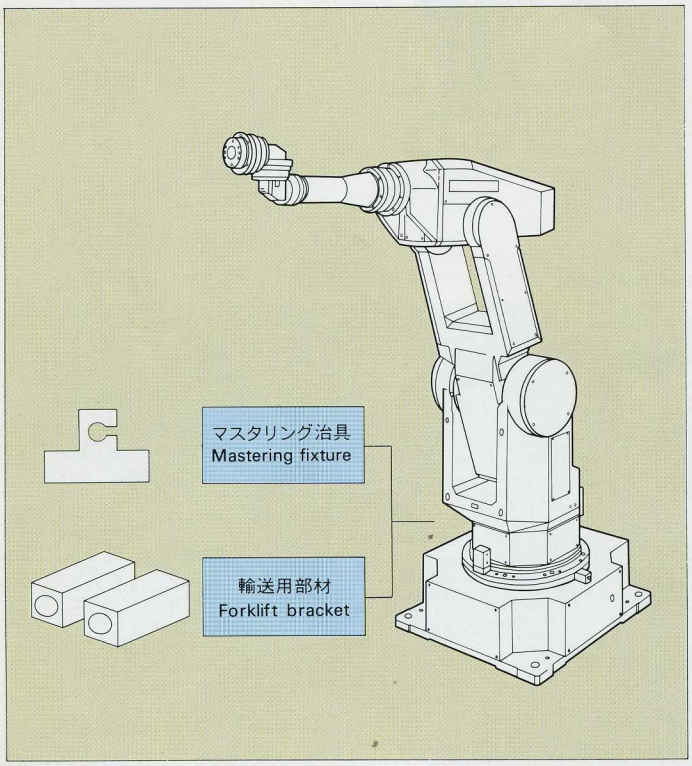
概　要

FANUC ROBOT S-MODEL 700は特に定置式スポット溶接へのワークのハンドリング（ハンドリングスポット）作業のために開発された手首可搬重量が30kgの6軸関節形多目的ロボットです。高い剛性と保守の容易な機構部は中量物ワークを扱うさまざまな作業に適用でき，新開発のディジタルサーボを搭載したR-G2コントローラと共に，将来にわたる工場の自動化に貢献します。

特　長

- 死角のない大きな動作領域でロボットの後方へのサービスもできます。さらに独特なバランス構造により，床置きのみならず，天吊り設置にも対応可能です。
- ベルト・キー類を一切使わない駆動系と全ての出力軸に減速機を直結した構造により，高い剛性と信頼性を確保しました。
- ロボットの機内ケーブルおよびモータを内蔵し，さらに完全に密封されたグリスバス方式の駆動機構により防塵・防水性が向上しました。
- モータが横に張り出さない構造のため，周辺機器をロボットの近くまで設置できます。また全軸にブレーキが装備されており，アラーム発生時や電源切断時にもロボットの姿勢を保持します。
- 純電子式絶対位置検出システムを採用しているため，電源投入後の原点復帰をする必要がなく，どんな現場でも自動的にロボットを始動することができます。
- 機構部にはマスタリング機能があり，ロボットの座標系を正確に設定することができます。

構　成　Configurations



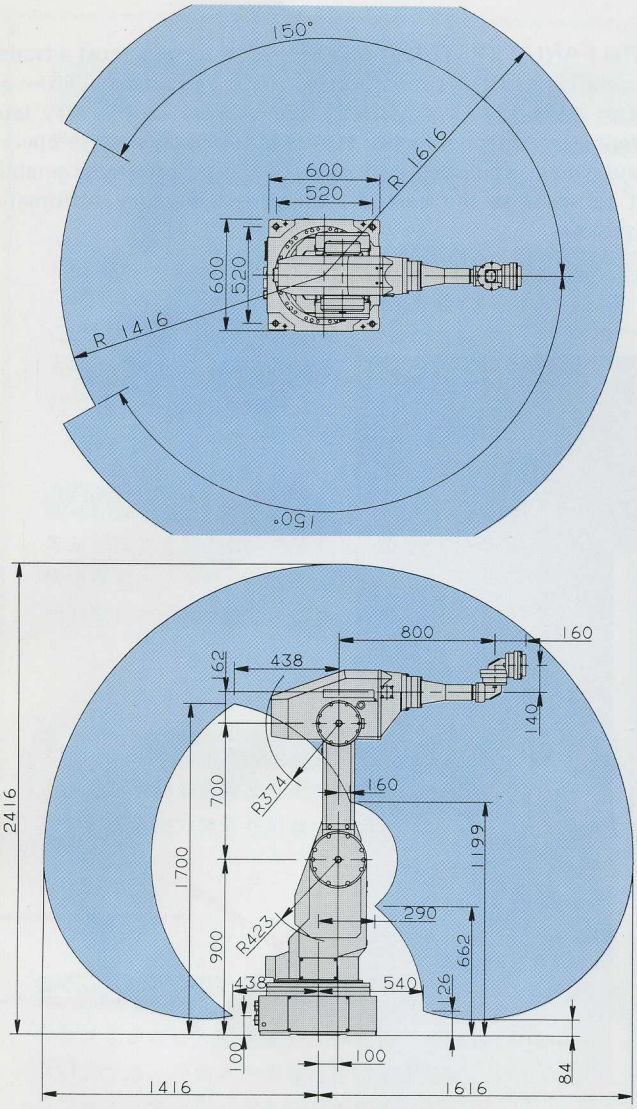
OUTLINE

The FANUC ROBOT S-MODEL 700 is a 6-axes articulated multipurpose robot with 30 kg payload specially developed for the handling-spotwelding applications.
The S-700 has a high-rigidity and ease of maintenance mechanism. It can be used for various kind of applications handled with middle-weight workpieces.

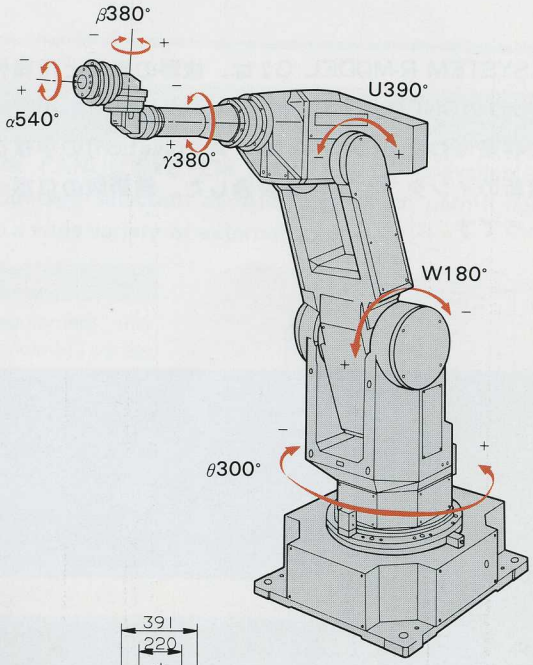
FEATURES

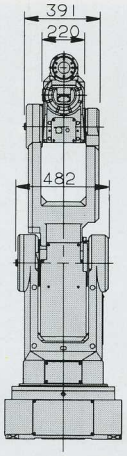
- A backside handling has been achieved with a dead zonless expansive operation range. The ceiling installation can be realized with the specific balanced mechanical structure.
- High-rigidity and superior reliability have been achieved through the direct-coupled joint structure without belts nor key driving elements.
- The cables and the motors are installed inside the mechanical unit, and the completely sealed grease-bath method is applied to the drive gears, which secured safer constructions against dust and water.
- The motors do not extend outward on either side of the robot. Peripherals can therefore be installed directly next to the robot. Also the robot position is automatically maintained by the safety brakes, in the case of mulfunctions or power failure.
- A fully electronic absolute position detection system eliminates the need for zero return operation after power on, and enables automatic start in any positions.
- The robot coordinate system is precisely set by the mastering fixture.

作動領域 Operating space



ロボットの動き Robot motion





仕　様

項目		仕様	備考
動作形態		多関節形ロボット	
制御軸		6軸(θ, W, U, γ, β, α)	
設置条件		床置、天吊	
動作範囲（最大動作速度）	θ軸旋回	300°(120°/sec)	
	W軸回転	180°(105°/sec)	
	U軸回転	390°(105°/sec)	
	γ軸手首回転	380°(180°/sec)	
	β軸手首振り	380°(180°/sec)	インライン手首：240°(180°/s)
	α軸手首回転	540°(240°/sec)	
手首部可搬重量		30kg	
駆動方式		ACサーボモータによる電気サーボ駆動	
位置繰返し精度		±0.2mm	JIS B8432による
重量		機構部　約500kg	
設置条件		周囲温度　0～45°C 周囲湿度　通常　75%RH以下 短期(1ヶ月以内)　95%RH以下 結露しないこと 振動値　0.5G以下	

Specifications

Item		Specifications	Remarks
Type		Articulated type	
Controlled axes		6 axes (θ, W, U, γ, β, α)	
Installation		Floor & Upside-down mount	
Motion Range (Maximum speed)	θ axis rotation	300° (120°/sec)	
	W axis rotation	180° (105°/sec)	
	U axis rotation	390° (105°/sec)	
	γ axis wrist swing	380° (180°/sec)	
	β axis wrist swing	380° (180°/sec)	Inline wrist: 240° (180°/s)
	α axis wrist swing	540° (240°/sec)	
Maximum load capacity at wrist		30 kg	
Drive method		Electric servo drive by AC servo motor	
Repeatability		±0.2 mm	Based on JIS B8432
Weight		Mechanical unit: Approx. 500kg	
Installation environment		Ambient temperature : 0 ~ 45°C Ambient humidity Normally 75% RH or less Short term Max 95% RH (within one month) No dew, nor frost allowed Vibration 0.5 G or less	