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PRACTICUM PAPER

An expert system for pneumatic design

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Abstract

One of the biggest problems in pneumatic system design is over design. Thus, the results are excessive in costs of the initial investment and it requires too much energy. This article describes the development of expert system based pneumatic design system, PNEUDES (PNEUmatic Design Expert System), prototype that enables the user the optimal design of pneumatic system. Once the design requirements such as cylinder type and work load, etc. are input to the system, optimal cylinder specifications with standardized order-based size, valves types, and necessary accessories are all determined. Also the configuration information such as the connectivity among components and cylinder image data are supplied to the user. It can also help the novice of pneumatic design. The rule-based reasoning approach is used as a reasoning strategy with Intelligent Rule Element shell.

Keywords: Pneumatic Design; Expert System; Rule; Design Requirement; Design Specification

1. INTRODUCTION

Pneumatics is the application of air-powered actuators (cylinders and motors) and the control devices (valves) needed in their operation. Modern pneumatics, with its versatile scope and chances, did not really begin to supplement established techniques using other forms of power or energy until about 1950 (Meixner & Kobler, 1990). Repeated releases of developments in equipment and announcements of ever newer fields of application prove that pneumatics is in a continuous process of growth. However, pneumatic energy is expensive in comparison with hydraulic or electrical energy because of production, storage, and distribution costs (Deppert & Stoll, 1986).

In general, design has typically been classified as being either the selection of components to form a skeletal design, the configuration of a given set of components, the fixing of numerical parameters, or the construction of designs from scratch (Hinrichs & Kolodner, 1991). Pneumatic system design also needs to select necessary pneumatic components, to determine their connectivity and component parameters.

There are several difficulties and problems to resolve in pneumatic design. First, there is the overdesign problem (SELECT, 1987). In spite of pneumatic technology, including much empirical knowledge, pneumatic design is sometimes performed by only using the technical information of the pneumatic manufacturer. Because there is lack of consistent pneumatic design methods, pneumatic engineering tends to only fulfill the design function that leads to overdesign. It results in excessive costs of equipment investment, and requires too much energy. Therefore, proper pneumatic design must be carefully performed (Barber, 1989). Second, the design itself is, in general, performed by pneumatic suppliers, so that customers cannot help just taking vendors' suggestions due to their lack of design knowledge. Third, pneumatic design knowledge could be obtained after at least three or four years of field experience. Fourth, pneumatic engineers usually use a company order catalog during design activity. Searching order numbers in catalogs is tedious. We believe that the expert system approach is the most appropriate solution to cope with these problems. Also this approach will provide users with benefits such as increased availability, increased reliability, fast response, intelligent tutor, etc. (Girratano & Riely, 1994).

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Research that has been carried out on pneumatics is limited to the design or performance estimates of the pneumatic cylinder itself (Brown & Chandrasekaran, 1985, 1992; Won, 1988). Research about the constitution of pneumatic systems or design methods is rare. We developed the knowledge-base system PNEUDES prototype to design a pneumatic system that manipulates a workpiece. The system's function is to determine the selection of pneumatic components, their connectivity among components as a configuration information, and of the model number (numerical parameter) of each component, etc. As the system inputs, design requirements such as work load, operating pressure, speed, moving direction, and mounting space of a cylinder, etc. are needed. PNEUDES also shows the picture of the selected actuator and pneumatic circuit diagram. The knowledge base is constructed by using handbook data and heuristic of pneumatic designer. The rule-based reasoning approach is adopted as a reasoning strategy.

2. PNEUMATIC SYSTEM

Compressed air is obtained by converting mechanical energy to pressure energy using an electrical motor or combustion engine. Pneumatics is used to manipulate various processes by regulating, controlling, and supplying compressed air. These pneumatic components refer to those operations, while the combination of pneumatic components is called a pneumatic system. The pneumatic system is basically composed of a pneumatic energy source, pneumatic signal input elements, pneumatic signal-processing elements, and actuating devices; the pneumatic signal flow among pneumatic components is shown in Figure 1 (Corser, 1989).

2.1. Linear pneumatic system

Linear operation in pneumatics is generally performed by pneumatic cylinders. A pneumatic cylinder is used to feed, supply, eject, lift, and clamp a workpiece with reciprocal movements. The piston of linear cylinder normally operates in the forward and backward direction with two-control position valves. When a middle-stop operation is needed, a three-control position valve is used. The role of flow-control valve and quick exhaust valve are to control the speed of piston. Accessories such as silencers, fittings, and tubes are operated with cylinders and valves.

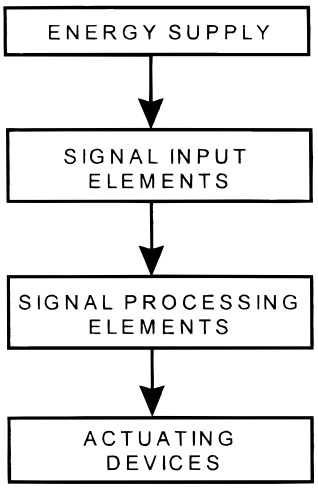


Fig. 1. Signal flow of pneumatic system.

2.2. Rotary pneumatic system

There are two kinds of elements in the rotary operation. One is the element of reciprocal rotational movement within the limited angle, such as on a rotary actuator with limited travel. The other has limitless rotational movement, such as a pneumatic motor. In general, a rotary actuator with limited angle is used in a pneumatic system. A vane-type rotary actuator directly creates torque by supplying pneumatic energy, and a rack and pinion type rotary actuator obtains torque by converting the linear movement of the piston rod to rotary movement. The torque of rotary actuator is determined by supplying pressure, area of piston and gear ratio, etc. A pneumatic rotary actuator is used to rotate elements and bending with reciprocal rotational movements. Valves related to speed control and accessories are also needed in a rotary pneumatic system.

2.3. Suction pneumatic system

The suction operation is performed with suction cup and vacuum pressure from vacuum generator. A suction cup is used for feed, assembly, and packaging, etc. The presence of vacuum is determined by supplying compressed air to the vacuum generator; therefore, a two-control position valve is used. Speed control is not necessary in a suction system; however, a silencer and other accessories are necessary.

2.4. Energy supplying components

From the viewpoint of the pneumatic designer, the final component of supplying compressed air is the service unit. The service unit consists of an air filter, a regulator, and a lubricator. The air filter gets rid of particles and condensed liquid. The pressure regulator is fitted downstream from the air filter, and has the task of keeping the operating pressure constant. The lubricator atomizes the oil, which then lubricates the pneumatic component.

3. SYSTEM STRUCTURE AND FUNCTION OF PNEUDES

3.1. Knowledge acquisition

We used handbook data and heuristics of design engineers as knowledge. Major heuristic knowledge comes from one of the authors who worked for FESTO Korea Ltd. as a pneu-

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matic engineer for 5 1/2 years. Other knowledge and data came from handbooks, catalogs, and discussion results with other pneumatic engineers.

3.2. Basic functions and structure of the system

PNEUDES for pneumatic design is developed by using an expert system approach. Thus, the inference engine and knowledge base were organized with system user interface. Figure 2 shows the basic structure of PNEUDES.

3.3. System construction strategy

3.3.1. Input management

The input management module's role is to receive design requirements from the user and convert them into the internal data. We have meta-knowledge that selects the appropriate knowledge base module according to the motion type of the actuator. Modularization of knowledge base is described below. The input window of PNEUDES is shown in Figure 3.

3.2.1. Reasoning strategy

Lots of pneumatic design knowledge could be expressed as rules and objects. Heuristic knowledge is stored as rules and pneumatic catalog data are expressed as objects. PNEUDES adopts forward reasoning because we expect the user could provide PNEUDES with sufficient input data, even though some wrong data may be included.

3.2.2. Modularization of knowledge base

We have pneumatic components such as linear and rotary cylinder, suction, and service unit. Therefore, we organized four modules of knowledge base according to these four classes. This strategy enables the knowledge base to be easily updated.

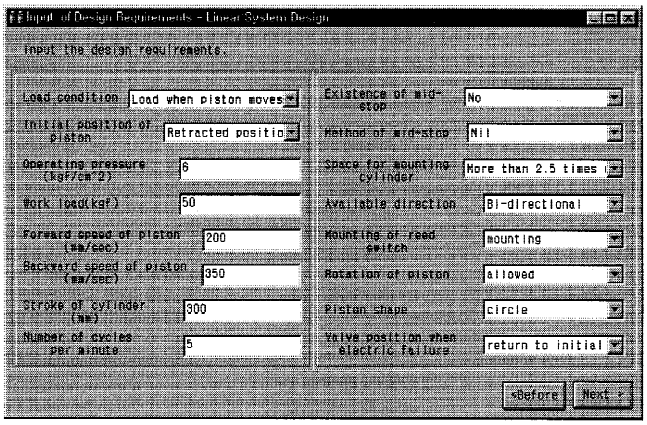


Fig. 3. The input window of PNEUDES.

In the knowledge base for the linear cylinder, we store rules for determining cylinder types, diameters, stroke, speed control method, the type and size of both solenoids and flow control valves, silencers, tubes, and fittings. Modularization of knowledge base can avoid the conflict of knowledge among these modules.

In case of rotary knowledge base there are rules for determining rotary actuator types, sizes, rotary angles, speed control methods, the type and size of both solenoid and flow control valve, silencer, tube, fitting and air consumption rate.

Rules for determining suction cup types and sizes, nozzle types and sizes, the types and sizes of solenoid valves, silencers, tubes, fittings and air consumption rates are included in the suction unit knowledge base.

Finally, the knowledge base for service unit contains rules for determining types and sizes of service units, tubes, and fittings.

There are 695 rules in linear knowledge base, 60 in rotary knowledge base, 70 in suction knowledge base, and 10 in knowledge base selecting service units. In the appendix, we list rules used for these knowledge bases.

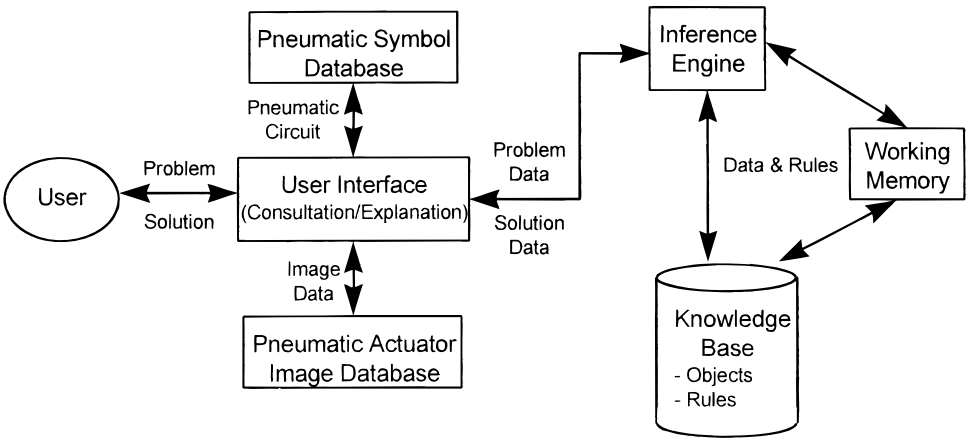


Fig. 2. The structure of PNEUDES.

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The connectivity knowledge is encoded as a procedural form in the system input manager using Visual BASIC language.

3.2.3. Utilization of pneumatic components catalog database

The pneumatic components produced by manufacturers have their own standards. In general, these standards are consistent with ISO standards. If someone wants a certain cylinder to output enough force, he can calculate the diameter of the cylinder using heuristic or deep knowledge in the pneumatic design area. Although one calculates the right specification, it is not common to purchase this cylinder with nonstandard diameter. Therefore, one must choose a little bigger standard diameter than the nonstandard one. The stroke of the cylinder also has limitations in diameter. These conditions are similar in the area of rotary operation and suction operation. Considering these conditions, PNEUDES outputs standardized catalog data that are stored in the computer. In case of the stroke of a cylinder, PNEUDES outputs in the same way, and outputs a message that pneumatic manufacturer can provide a special ordered stroke if customers want it. We also have a pneumatic symbol database that will be used for displaying pneumatic diagram.

3.2.4. Output management

Once the inference engine finishes its reasoning, it calls the output manager to show two kinds of results. First, the text editor is prepared for showing design specifications of components retrieved. If the actuator is selected as an output, the graphic image is also displayed to help verify component shape. Figure 4 shows the determined design specification of the cylinder with its graphic image. We have more than 20 actuator images in the system. Second, the connectivity information among selected components is displayed. By using this connectivity, the user can link air tubes among components.

3.2.5. Explanation

If there is a failure in firing rules after receiving design requirements, this means pattern matching fails and there is erroneous input data. In this case PNEUDES halts to execute and provides user with a message saying the place and reason why it refuses to run further. Issuing this message about the nonstandardized cylinder parameter is another function of the system during output managing process. The "why" and "how" explanation for reasoning process is still under development.

3.2.6. Development environment of PNEUDES

PNEUDES runs on Windows 95. Intelligent Rule Element is used as an expert system shell. Visual Basic 4.0 is also used for the system user interface.

4. APPLICATION EXAMPLE OF PNEUDES

For validating PNEUDES, we compare the design results of PNEUDES with that of design pneumatic design engineer for the same design problem. Two case studies are described in this article. It shows that the design specification of PNEUDES does not allow overdesign. Also the standardized cylinder parameter is quickly generated.

4.1. CASE 1: Machining line of caliper housing

The caliper housing belongs to the brake system in a car. The machining line of a caliper housing consists of a pneu-

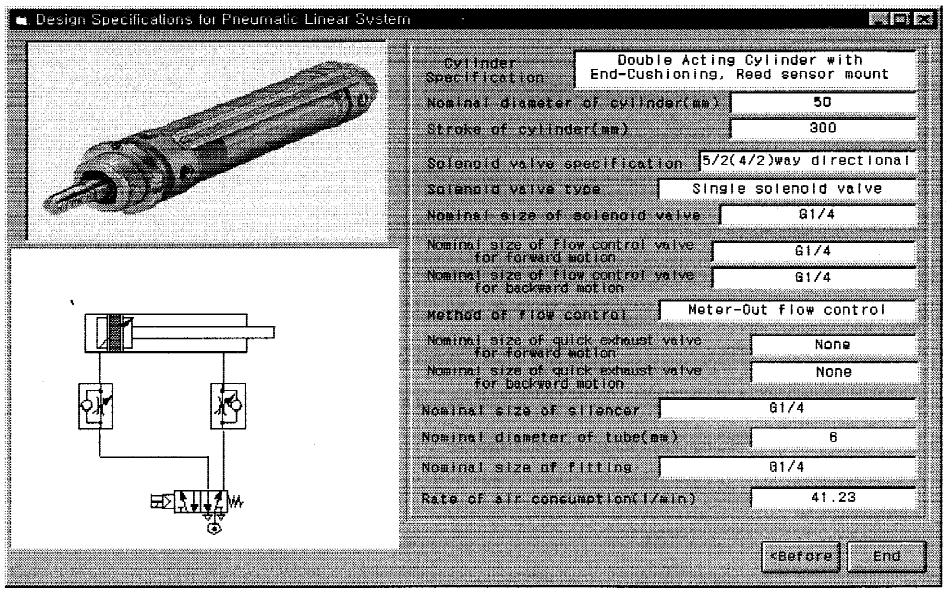


Fig. 4. The output window of PNEUDES.

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matic system that does feeding, clamping, and lifting operations. The layout of the pneumatic components in the machining line of a caliper housing is shown in Figure 5.

There are three kinds of cylinders in the pneumatic system. The first is two linear drives that feed the workpiece by turns; the second is two clamp cylinders that fix the pallet; and, the third is the lifter cylinder that transports the pallet to conveyer2. The motion-sequence of cylinders can be easily understood by using a motion-step diagram, that is commonly used for motion sequences in the pneumatic and hydraulic fields. This diagram represents the operating sequence of the actuators; the displacement is determined according to the sequence step. A motion step diagram of the pneumatic system in the caliper housing machining line is shown in Figure 6.

The design specifications of a caliper housing machine lines, previously designed and currently in use in an industrial field, are compared with that of the PNEUDES. The results are as follows.

4.1.1. Clamping cylinder

PNEUDES results and the engineer's design specifications are almost the same for the clamp cylinder and its related pneumatic components. In the engineer's design, the fittings of flow-control valve (G1/4) and the solenoid valve (M5) are different. In the case of a designer who desired a stroke of 35 mm, PNEUDES output is 40 mm. The reason is that a 35 mm stroke is not a standard stroke, so PNEUDES outputs a stroke consistent with the catalog and shows the comment that a 35-mm stroke is available by order. The comparison about design specifications of clamp cylinder is shown in Table 1.

4.1.2. Lifting cylinder

PNEUDES and engineer's results are almost the same for the lifting cylinder and its related pneumatic components except for the solenoid specifications and the flow-control valve specifications. Therefore, the reducer must be used to connect the solenoid valve and the flow-control valve. As in the case of the clamping cylinder, the designer wants 370 mm, but 400 mm is provided as result of PNEUDES.

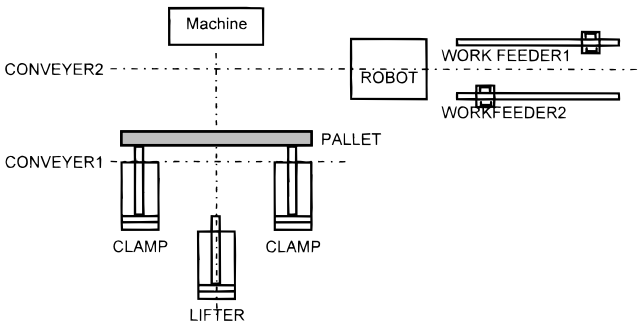


Fig. 5. Layout of pneumatic components in caliper housing machining line.

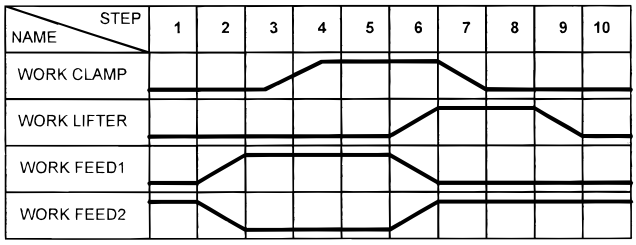


Fig. 6. Motion-step diagram.

Because 370-mm stroke is not a standard stroke, PNEUDES outputs 400-mm stroke as the standard stroke specification. In this case the message that a 370-mm stroke is available by order also appears on the screen. Table 2 shows the comparison about design specification of lifting cylinder.

4.1.3. Feeding cylinder

PNEUDES results and engineer's design specifications are the same for the feed cylinder and its related pneumatic components. The comparison about design specifications of feed cylinder is shown in Table 3. The result is almost the same for the pneumatic system in caliper-housing machining line when compared the results of PNEUDES and engineer's design specifications. The installed pneumatic system uses a common manifold block to treat the supply line and the exhaust line, so that we cannot compare the silencer specification directly. The fitting size of the silencer used in machining line of caliper housing is G1/2 so as to exhaust the air from the five cylinders, but the PNEUDES outputs silencer specifications separately. Additionally, PNEUDES provides the user the air consumption rate for helping to select a service-unit specification. The installed pneumatic system uses common manifold block to treat the supply and exhaust line, so that we cannot compare the silencer specification directly. The fitting size of the silencer used in machining line of caliper housing is G1/2 so as to exhaust air from the five cylinders, but PNEUDES outputs silencer specification separately. Additionally, PNEUDES generates the air consumption rate, that helps the user to select a service-unit specification.

4.2. CASE 2: Packing line of refrigerator

In this study, assembled refrigerators are transferred to packaging line by conveyor belt. At this time, refrigerators are laid down on the belt to take the stabilized posture. A gantry-type robot at the packaging line stands a refrigerator by the help of four suction cups on robot hand. The design specifications of pneumatic suction system in a gantry robot, previously designed by pneumatic engineer and currently in use, are compared with the results of PNEUDES. The comparison is shown in Table 4. The result of PNEUDES and engineer's design specifications are the same except for cup size and its related components. We suppose that the differ-

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Table 1. *Comparison of clamping cylinder design specifications*

Design requirements		Design specifications		
Attribute	Attribute value	Attribute	Engineer	PNEUDES
motionType	linear	Tube	6	4
pressure	5	Stroke	35	40
numOfPosition	two	SV_type	Single	Single
midStop	nil	SV_spec	5/2	5/2(4/2)
worktype	after	SV_size	M5	G1/8
workLoad	40	Silencer	—	G1/8
speed_f	50	QEV_f	None	None
speed_b	50	QEV_b	None	None
stroke	35	Flow_control	Meter_out	Meter_out
mountSpace	free	FCV_f	G1/4	G1/8
available FB	forward	FCV_b	G1/4	G1/8
mountReed	reed	Fitting	G1/4	G1/8
pistonRot	notrot	Diameter	40	40
pistonShape	circle_guide	Air_consp	—	1.21
el_failure	return	Actuator	NRSSDAC _RD	NRSSDAC _RD
cycles	2			
cyl_Init	In			

ence of design specifications about cup size and its related components is due to overdesign of engineer. Thus, we can decrease the cost 41% for the pneumatic suction system in gantry robot using PNEUDES. The cost calculation is based on the market price of a FESTO Korea Ltd.

5. CONCLUSIONS

We described in this article what pneumatic design is, what kind of problem it has such as the overdesign, the function and structure of PNEUDES prototype what we developed for pneumatic system design to resolve current industry problems, and two case studies. From these case studies we could verify the validity of PNEUDES in a prototype level. The graphic pneumatic connectivity diagram and cylinder image, for the easy and clear understanding, are also displayed with selected design specification of the pneumatic components. The why/how explanation function is still under development. The knowledge base was organized by four types of modules according to actuator type and service

Table 2. *Comparison of lifting cylinder design specifications*

Design requirements		Design specifications		
Attribute	Attribute value	Attribute	Engineer	PNEUDES
motionType	linear	Tube	6	9
pressure	5	Stroke	370	400
numOfPosition	two	SV_type	Double	Double
midStop	nil	SV_spec	5/2	5/2(4/2)
worktype	on	SV_size	G1/4	G3/8
workLoad	100	Silencer	—	G3/8
speed_f	200	QEV_f	None	None
speed_b	200	QEV_b	None	None
stroke	370	Flow_control	Meter_out	Meter_out
mountSpace	free	FCV_f	G3/8	G3/8
available FB	forward	FCV_b	G3/8	G3/8
mountReed	reed	Fitting	G3/8	G3/8
pistonRot	rot	Diameter	80	80
pistonShape	circle	Air_consp	—	48.25
el_failure	memory	Actuator	DAC_EC _RD	DAC_EC _RD
cycles	2			
cyl_Init	In			

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Table 3. *Comparison of feeding cylinder design specifications*

Design requirements		Design specifications		
Attribute	Attribute value	Attribute	Engineer	PNEUDES
motionType	linear	Tube	6	6
pressure	5	Stroke	1130	1130
numOfPosition	two	SV_type	Double	Double
midStop	nil	SV_spec	5/2	5/2(4/2)
worktype	on	SV_size	G1/4	G1/4
workLoad	50	Silencer	—	G1/4
speed_f	350	QEV_f	None	None
speed_b	350	QEV_b	None	None
stroke	1130	Flow_control	Meter_out	Meter_out
mountSpace	limited	FCV_f	G1/4	G1/4
available FB	bi_directional	FCV_b	G1/4	G1/4
mountReed	reed	Fitting	G1/4	G1/4
pistonRot	notrot	Diameter	40	40
pistonShape	circle_guide	Air_consp	—	34.08
el_failure	memory	Actuator	NRLD_EC _RD	NRLD_EC _RD
cycles	2			
cyl_Init	In			

unit. As far as a reasoning strategy, we adopted the rule-based reasoning (RBR) system even we had envisaged at the beginning of this research and the case-based reasoning (CBR) paradigm. Due to the difficulties of acquiring variety of previous cases, we changed to RBR on that we could easily collect design heuristic. Much of heuristic knowledge has been provided by one of the authors having experience with the pneumatic industry. Even though the system still has some deficiencies, after some more elaboration, we expect PNEUDES could be successfully used by the pneumatic design personnel of both system suppliers and customers.

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Table 4. *Comparison of design specifications about pneumatic suction system in a gantry robot*

Design requirements		Design specifications		
Attribute	Attribute value	Attribute	Engineer	PNEUDES
motionType	suction	Tube	9	6
workpieceHardness	hard	SV_type	Double	Double
workpieceShape	flat	SV_spec	3/2	3/2
workpieceSurface	notsticky	SV_size	G3/8	G1/4
handlingStatus	vertical	Silencer	G3/8	G1/4
numOfCup	4	numOfCup	4	4
workLoad	50	Nozzle_type	NSN	NSN
el_failure	memory	Fitting	G3/8	G1/4
on_time	10	Cup_type	Normal	Normal
		Cup_size	150	95
		Cup_material	PU	PU
		Air_cons	—	50

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APPENDIX

A1. Rules in linear knowledge base

The knowledge base used for the design of pneumatic linear operation contains the following types of rules:

- Rules for the limit of operation pressure.
- Rules for the limit and estimation of piston speed.
- Rules for the limit and estimation of strokes.
- Rules for the limit and estimation of force.
- Rules for the determination of safety factors.
- Rules for the estimation of middle-stop of piston.
- Rules for the rotation of piston rods.
- Rules for the estimation of shape of piston rods.
- Rules for the estimation of forward or backward movement of pistons.
- Rules for the estimation of piston movement with or without load.
- Rules for the determination of diameter and specification of cylinders.
- Rules for the determination of strokes.
- Rules for the estimation of mounting space of cylinders.
- Rules for the estimation of reed-switch mounting.
- Rules for the determination of flow-control methods.
- Rules for the determination of solenoid-valve specifications.
- Rules for the determination of flow-control valve or quick-exhaust valve specification.
- Rules for the calculation of air consumption.
- Rules for the determination of pneumatic accessories specification.
- Rules for the availability of pneumatic elements database, etc.

A2. Rules in rotary knowledge base

The knowledge base used for the design of pneumatic rotary operation contains the following types of rules:

- Rules for the limit of operation pressure.
- Rules for the limit and estimation of torque.
- Rules for the determination of safety factor.
- Rules for the limit and estimation of rotational angle.
- Rules for the estimation of reed-switch mounting.
- Rules for the determination of rotary actuator specification.
- Rules for the limit and estimation of piston speed.
- Rules for the determination of solenoid-valve specification.
- Rules for the determination of flow control-valve specification.
- Rules for the calculation of air consumption.
- Rules for the determination of pneumatic accessories specification.
- Rules for the availability of pneumatic elements database etc.

A3. Rules in suction knowledge base

The knowledge base used for the design of pneumatic suction operation contains the following types of rules:

- Rules for the limit of operation pressure.
- Rules for the limit and estimation of suction force.
- Rules for the determination of suction cup specification.
- Rules for the determination of safety factors.
- Rules for the increment of the number of suction cups.
- Rules for the determination of vacuum-nozzle specification.
- Rules for the determination of solenoid-valve specification.
- Rules for the calculation of air consumption.
- Rules for the determination of pneumatic accessories specification.
- Rules for the availability of pneumatic elements database etc.

A4. Rules in selection knowledge base of service unit

The knowledge base used for the selection of pneumatic service unit contains the following types of rules:

- Rules for the limit of operation pressure.
- Rules for the estimation of pneumatic system air consumption.
- Rules for the determination of service unit specification.
- Rules for the determination of pneumatic accessories specification.
- Rules for the availability of pneumatic elements database etc.

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