HMS ARM COMPONENTS

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Summary

For arm systems developed at the Rehabilitation Engineering Department (HMS) of the Karolinska Hospital, Stockholm, commercially available components are used as far as possible. If the components available do not meet our requirments four kinds of development may occur:

1. *The supplier of the component improves the component according to our specifications.*
2. *We improve the component ourselves*
3. *A new component developed by us when improvement of available components is not possible.*
4. *A unique component is developed if the desired function and characteristics are not represented on the market.*

High demands are always put upon reliability and life time of the components, and all components used in our systems are subject to cycling tests.

The components, as listed and specified in this paper, fall into the following cathegories

Power supply.
Components for the control of prostheses.
Powered joints.
Passive joints.
Structural components.

Most of the components for powered systems are pneumatic, although some electric components are used.

Introduction

The Rehabilitation Engineering Department of Karolinska Sjukhuset (Karolinska Hospital), Stockholm, is a new department responsible for research development, production or purchasing, and fitting of aids for the handicapped. The larger portion of the work within the department is related to orthopaedic aids, e.g. prostheses, orthoses, corsets, orthopaedic shoes.

The department was from the beginning formed by reorganization of the former prosthetic research laboratory, and the orthopaedic workshops of the Norrbacka Institute (NBI),

Since 1964 the prosthetic research laboratory has carried on research and development within the field of pneumatic arm prostheses for high level amputees. The initial goal was to make better arms for the thalidomide children. The current work is focusing on children as well as adults.

From the very beginning we applied a systems approach, where commercially available components should be utilized as far as possible. In cases where components were not available to put together the systems we were striving for, we had to start development. For various reasons we focused our own work, as far as components were concerned, on the control.

We had some initial success, although this success probably must be related to an admirable tolerance from children as well as from their parents. The early components served the purpose of making it possible to build systems that in fact moved, but their general characteristics and their durability were far from acceptable.

After having finished the initial experiment with pressure demand valves we immediately concentrated on making reliable and reproduceable components. At any case where a choice between beautiful characteristics and reliability was available, the reliability was chosen.

We felt that if the systems had to be realistic, this also meant that the components had to be realistic. The question of size of the components is very important. Bulky valves can spoil the image of the prosthesis and thus the image of the patient, and would then be likely to lead to rejection of the prosthesis. We thus, from the very beginning, also put higher priority on size than on nice characteristics.

This leads to another concept which is very often discussed in engineering development. Often times the approach is taken that the first prototypes are made in large scale, and when adequate function has been verified, miniaturizing starts. We have felt that this first step of making a prototype in large scale often is useless, as the real problems will introduce themselves during the process of miniaturizing. We have therefore each time made our prototypes in real scale.

When using our control components in prosthetic systems we very soon found that commercially available arm compnents and also previous designs of our own were not sufficient, and we therefore had to improve the commercially available components or to develop new components for elbows, shoulders etc. These improvments can be minor or major, but they often turn out to deal with things like improving bearings and links.

As the systems became more complex, new parts like upper arms, shoulder joints, etc. that did not exist on the market had to be developed.

The result of all this is that we can now build reasonably strong and reliable pneumatic arm systems using a combination of our components and components that are commercially available and in certain cases improved us.

Besides the development of components for pneumatic arms some passive parts for all kinds of arms have been developed, and also some components for the control of electric prostheses.

In summary the four kinds of development that we are involved in are:

1. The supplier of the component improves the component according to our specifications.
2. We improve the component ourselves
3. A new component is developed by us when improvement of the available components is not possible or convenient.
4. A unique component is developed if the desired functions and characteristics are not represented on the market.

Unfortunately established methods for lifetime tests have not been available, so we have had to develop our own methods and equipment. We have thus designed and built a mechanical programming device that gives input to pneumatic valves or electric switches. The inputs can be force or displacement, and five parallel, synchronized channels are available.

For all active components, e.g. valves and actuators, we expect and document at least 300,000 cycles at full load. For passive components we expect and document 100,000 cycles at full load. For control components we in fact expect higher lifetime as many of them can be of interest for more general industrial applications. Industries are now running experiments with our valves in order to include them in their own systems. The pressure demand valves thus have been tested for more than a million cycles without any failure.

The HMS arm components fall into the following categories:

Power supply.

Components for the control of the prostheses.

Powered joints.

Passive joints.

Structural components.

Miscellaneous.

Hundreds of components have been developed, but for various reasons many of them are no longer of interest. In this paper only the selected components, that are used in our own systems, will be mentioned.

We have been fourtunate to have active patients available, and we feel that our collaboration with these patients has been of mutual benifit. The ways these patients use their prostheses tell us that they have been reasonable successful and they give us further information about improvements that are required or new possibilities.

The name NBI on the identification of the components is obvious from the history of the Rehabilitation Engineering Department.

Components for Pneumatic Power Supply

NBI-PR-2

Pressure reducer NBI-PR-2 is a compact pressure reducer designed for the original Heidelberg gas container. It can easily be modified for any container. The pressure reducer has no closing valve, but is supplied with a safety valve on the output side. About fifty have been made, fifteen of them of the latest version. In the latest version the pressure is easily adjusted.

Input pressure:	30-100 bar
Output pressure:	5- 40 "
Connection, input side:	M8 x 0,75 male thread
" , output:	ID 1 mm tubing
Diameter:	30 mm
Length excluding thread:	14,5 mm
Length including thread:	21,5 mm
Weight:	59 grams

NBI-PD-10/2-PRA

NBI-PD-10/2-PRA is an adapter that converts the pressure demand valve NBI-PD-10/2 to a pressure reducer. It is used where a prosthetic system involves actuators with different supply pressures so that the main pressure reducer can be adjusted for the highest pressure that occurs in the system.

Diameter: 23 mm
Length, including valve: 17 mm
Pressure: see valve NBI-PD-10/2

Contol Valves and Adapters

Pressure demand valves

The NBI pressure demand valves are valves with an internal feed-back so as to give output pressure proportional to the input force. They combine the upstream and the downstream function in a three way control of a pneumatic actuater (1,2). Three sizes have been developed, of which two are used on our patient systems. The biggest version, NBI-PD-10/2 has a typical piston diameter of the feed-back piston of 10 mm (approximately 10 mm active diameter of the membrane version) and a typical diameter of 2 mm of the biggest hole in the concretic internal channel system.

Three different functions are available as far as the bigger versions are concerned, namely, one version which provides stop when there is no input force (e.g. NBI-PD-10/2-1S), one version which opens the exhaust when there is no force on the input (NBI-PD-10/2-1) and finally one version with no exhaust (NBI-PD-10/2-1 +). This latter version thus requires a separate exhaust valve for the actuators.

The same versions occur for the NBI-PD-5/1. The smallest valve, NBI-PD-2/0,5-1S only occurs in one version, namely the one with closing at no input signal.

In summary seven different pressure demand valves have been developed and selected, namely:

NBI-PD-10/2-1
NBI-PD-10/2-1+
NBI-PD-10/2-1S
NBI-PD-5/1-1
NBI-PD-5/1-1+
NBI-PD-5/1-1S
NBI-PD-2/0,5-1S

For the specifications see Table 1.

Table 1

Valve	Flow NL/min in	out	Pressure bar/N	Stop N/bar	Pressure bar, max.	Diameter mm	Length mm	Connections (ID of tubing)	Weight grams	Number produced
NBI-PD 10/2-1	30	30	0,1	-	(12) 20	23	6,5	1 mm		75
NBI-PD 10/2-1S	30	30	0,1	4,2	(12) 20	23	6,5	1 mm	5,5	
NBI-PD 10/2-1+	30	-	0,1	-	(12) 20	23	6,5	1 mm		
NBI-PD 5/1-1	7	7	0,6	-	20	17	5	1 mm		
NBI-PD 5/1-1S	7	7	0,6	1,1	20	17	5	1 mm	3,0	100
NBI-PD 5/1-1+	7	-	0,6	-	20	17	5	1 mm		
NBI-PD 2/0,5-1S	2,6	2,6	0,5	0,15	12	18	11	1 mm	6,0	5

(-) max. pressure membran type

NBI pressure demand valves

NBI-LA

This is an adapter to be applied on a pressure demand valve in order to connect the valve to the control site of the patient's body. Two sizes are available, namely one for the NBI-PD-10/2-series and one for the NBI-PD-5/1-series. The NBI-PD-2/0,5-1S has an integrated adapter.

A typical identification code for a valve and an adapter is NBI-PD-10/2-1S-LA. The total height of the valve plus adapter is 9 mm. The diameter is the same as the diameter of the valve. The lever sticks out radially from the adapter. Depending on application there is a force ration in the adapter of about 5:1. The force required on the adapter is thus about five times smaller than the force required on the valve.

NBI-PSU

NBI-PSU is a position servo unit that provides a mechanical connection between the actuator and the valve, so that the valve follows the movement of the actuator. The lever on which the valve is attached on the unit moves $1,2^{0}$ per mm displacement of the connection to the actuator.

<u>Various Components for Pneumatic Control Systems</u>

NBI-DPS-1

NBI-DPS-1 is a differential pressure sensor, originally designed to be used in automatic lock systems. It thus senses if the pressure of two different systems are equal or not. If the pressures are equal supply pressure is available from an output on the DPS. If the pressures are not equal, this connection is exhausted instead. If it is used for an automatic lock system, at equal pressures a lock may be actuated and a by-pass valve may be closed, while when the pressures are not equal the lock opens and the by-pass valve also opens.

Connections are for ID. 1 mm tubing (five connectors).

Diameter:	30 mm
Length:	15 mm
Minimum pressure difference:	0,4 bar

NBI-PA-20/3

NBI-PA-20/3 is a power amplifier with a ration between input pressure and output pressure of 1:1. It is used to increase the speed of the actuator and not to increase the force.

Diameter:	24 mm
Length:	12 mm
Connections output and input ID:	2 mm tubing
Control input ID:	1 mm "
Max. flow:	90 NL/min at 7 bar
Max. pressure:	10 bar

NBI-BP2-1

NBI-BP2- 1 is a pneumatically controlled on-off by-pass valve, which squeezes the tubing when control pressure is applied. The component is thus applied on the Vucolan tubing itself, and therefore it gives no restriction when the valve is open.

Diameter:	14 mm
Length:	12 mm
Connections: tubing ID	1 mm) is threaded through
" OD	2 mm) the valve
input for control ID	1 mm tubing

NBI-BP2-2

NBI-BP2-2 is similar to NBI-DP2-1 except that it is made for 2 mm i.d. (o.d. 4 mm) tubing.

Diameter:	16 mm
Length:	16 mm
Connection: tubing ID	1 mm) is threaded through
OD	2 mm) the valve
input for control ID	1 mm tubing

NBI-AR-1

NBI-AR-1 is a continuously variable pneumatic resistor. It can be set down to zero flow and can be adjusted from outside when connected to the pneumatic system. The flow through the resistor is straight.

Diameter	5 mm

Length excluding connectors:	9 mm
Weight:	1,3 gr
Connections: ID	1 mm tubing

NBI-OW-1

NBI-OW-1 is a non return valve.

Diameter:	4 mm
Length excluding connectors:	7 mm
Weight:	0,6 gr
Connections: ID	1 mm tubing

NBI-FI-1

NBI-FI-1 is a filter inhabiting particles larger than 15/u mm.

Diameter:	12 mm
Length excluding connectors:	8 mm
Connections: ID	1 mm tubing

NBI-S-M5

NBI-S-M5 is a silencer to be connected on the exhaust of the valve or actuator.

Connection M5 has male threads.

NBI-C1-1, NBI-C2-1, NBI-C3-1, NBI-C4-1 and NBI-C5-1 -1

These are 1-5 way connectors for 1 mm tubing. NBI-C1-1 is designed to fit to any valve with a standardized press fit. NBI-C2-1 has a diameter of 4 mm and a length of 12 mm. NBI-C3-1, NBI-C4-1 and NBI-C5-1 have an outside diameter of 8 mm and a length of 12 mm.

NBI-C1-2, NBI-C2-2

These are similar to the connectors for 1 mm tubing but designed for ID 2 mm tubing.

NBI-C2-1 x 2

NBI-C2-1 x 2 is a connector that transmits from 1 mm tubing to 2 mm tubing.

Components for Control of Electric Prostheses

Three-State Switch

This switch is designed to pick up bulging muscles or moving joint. It has a flat configuration in order to enable good cosmetic appearance. The force as well as the displacement can be adjusted. At first level (switch released) there is no signal, at the second level there is a signal in one direction and at the third level the switch supplies the opposite signal.

Dimensions:	36 x 32 x 8 mm
Weight:	17 gr

Sequential Switch

This is a switch to be connected to a conventional shoulder harness to enable control of electric hands. The force required to initiate the signal of the switch can be adjusted. The switching between positive and negative direction is supplied by a separate electronic unit that switches between a positive and a negative direction of the output signal each time it receives an input signal.

Dimensions of switch: 26 x 35 x 8 mm

" " electronic unit are similar to the dimensions of the Viennatone MM3 amplifier.

Powered Joints

Pneumatic Elbow for Children 8-14 Years

This is a pneumatic elbow powered by a differential cylinder. In our applications three-way control has been used but four-way control is also possible.

Connections:	proximal end for upper arm shell ID distal end for Otto Bock lower arm shell:	54 mm
Dimensions:	diameter:	54 mm
	length from top to shaft including passive upper arm roatation:	130 mm
Weight:		350 gr

Flexion moment max.: (4 Nm in end position)	8 Nm
Extension moment max.: (1 Nm in end position)	2 Nm
Range of movement:	135°
Pressure:	7 bar
Power consumption:	0,32 g CO_2 / stroke at 7 bar

Pneumatic Elbow for Children 5-8 Year

This is a pneumatic elbow powered by a differential cylinder. In our applications three-way control has been used but four-way control is also possible.

Connections:	proximal end for upper arm shell ID distal end for special lower arm shell:	40 mm
Dimensions:	diameter:	40 mm
	length from top to shaft including passive upper arm rotation:	65 mm
Weight:		85 gr
Flexion moment: (0,5 Nm in end position)		1 Nm
Extension moment: (0,5 Nm in end position)		1,2 Nm
Range of movement:		135°
Pressure:		7 bar

Pneumatic Elbow for Children 5-8 Year, with Linked Wrist Rotation

This elbow is used and supplied with a link that is connected to a modified Otto Bock pneumatic wrist turner, where the pneumatic piston has been removed. Elbow flexion of 130° gives 180° wrist rotation.

Shoulder Joint with Pneumatic Lock for Adults

A shoulder ball joint with pneumatic lock has been developed. The joint is free swinging and can be locked in any position.

Connections:	tubing ID	1 mm
Dimensions:	diameter:	50 mm
	length:	40 mm
Weight:		82 gr
Lock moment:		12 Nm
Power consumption:		0,01 g CO_2 / locking at 7 bar

Upper Arm Rotation for Children

A device that converts the Otto Bock pneumatic wrist rotation **unit** for children to a humaral rotation device has been **developed.**

Connections: proximly end for Otto Bock pneum. wrist turner for children
distal end for Otto Bock pneum. elbow for children

Dimensions:	diameter	54 mm
	length including motor:	92 mm
Weight:		82 gr

Passive Joints

Shoulder Ball Joint for Adults

This is a friction joint, where the friction can be set **from free** swing to total locking.

Diameter:	60 mm
Length:	41 mm
Weight:	115 gr

Shoulder Ball Joint for Children

Similar to the previous one but for children.

Diameter:	50 mm
Length:	30 mm
Weight:	55 gr

Wrist Flexion Joint for Adults

This is a wrist flexion joint that can be set in seven positions from 51° wrist flexion to 51° hyper extension of the wrist.

Connections: M12 x 1,5 thread, male in the prox. end and female in the distal end. (Can be supplied with pneumatic connection for Otto Bock pneum. hands and hooks or connection for electric hands).

Diameter :	53 mm
Length: (including thread)	50 mm
Weight:	70 gr

Wrist Flexion Joint for Children

This is a child size of the previous item, but with only two locking positions, namely 45° flexion and 5° hyper extension of the wrist.

Connections: M12 x 1,5 thread, male in the prox. end female in the distal end. (Can be supplied with pneumatic connection for Otto Bock pneum. hands and hooks or connection for electric hands).

Diameter:	40 mm
Length: (including thread)	39 mm
Weight:	35 gr

Structural Components

Upper Arm Shells

Upper arm shells designed for the various shoulder joints mentioned above and to be connected to Otto Bock or our own elbow joints have been developed. For adults an upper arm shell, with space for a Heidelberg IQA gas container is available. When using these shells the distal end can be cut to any convenient length.

Availability

All components mentioned above, except the pressure demand valve NBI-PD-2/0,5-1S and the differential pressure NBI-DPS-1, are available upon request.

References

/1/ Klasson, B.; "Development on Externally Powered Artificial Arms at NBI", *Proceedings of the International Symposium on External Control of Human Extremities"*, Dubrovnik 1966, Yugoslav Committee for Electronics and Automation, Belgrade 1967.

/2/ Klasson, B.; "Development of Components for the Control of Pneumatic Prostheses - Background, Current Status and Future Plans", *Prosthetics International*, Vol. 3, No. 10, 1970.