HOLLOW ROD Hy-P ACTUATORS and THIER APPLICATIONS IN AIRCRAFT MANUFACTURING

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In May of 2006 RB Hybro Dynamics developed and first introduced new series of linear Hy-P actuators with **hollow rods**. These actuators were specifically developed to as thrust units in drilling, countersinking and rimming operations at Boeing plant in Everett, Washington.

The business of drilling large variety of precision holes is and always was a big part of aircraft construction process. In today's manufacturing practice the drilling is required to be productive, consistent, ergonomic, cost effective, and often to take place in the most cumbersome areas, through geometrically irregular surfaces and multiple layers of various materials with different properties, such as aluminum, titanium, carbon fiber composites, etc. Although the development of new and upgrade of existing drilling methods and associated drilling equipment is perpetuating for the industry, in the late 90s the manufactures felt a need to accelerate it. That along with design of large composite body airplanes produced a demand, which resulted in creation of several drilling systems of a new generation utilizing Hy-P Actuation.

I. Conventional versions of Hand Held Drilling Systems - Flaws and Advantages

The entire park of drilling equipment used by the industry could be conditionally divided into three main groups: fully automatic machines, hand held automated drilling systems and manual power tools. The majority of drilling processes employ hand held automated drilling systems. These systems are predominantly air powered for the following reasons: high specific power of pneumatics (averaging 1.2 to 1.85 hp/lb) and it's compactness, relatively safe operation at the customarily accepted 90 PSI of pressure, reasonable cost to acquire and maintain, relatively simple construction (with deriving high reliability), high maltreatment forgiveness, ability to reliably operate in harsh working environment (vibration, shock, coolants and oils, composite dust, metal chips, etc.), centralized power supply, ability to cover most of the required functions with just one form of power (without power conversions). Although, the named reasons are not the only ones to explain the preference for pneumatic power, they are however, generally agreed upon as being the most important for the industry.

A typical construction of a conventional hand held automated drilling system begins with having a pneumatic motor with a gear head. Because the motor with the gear head are responsible for the main function of drilling, these two coupled components can be considered as the **core sub-system** or the **main sub-system** of the entire unit. The majority of such motors used by the industry generate power within the range of 0.6 to 2 hp. The motors and the accompanying gear heads both are very light (motors weigh 0.75 to 1.1 lb; gear heads weigh 0.4 to 0.55 lb) and compact.

The drilling systems further include secondary **sub-system**s; the number and selection of which varies from system to system depending on the set of functions it is required to perform. However, as of today the list of possible sub-systems includes: **anchor** of different optional constructions (for clamping the system to the object of drilling), **thrust unit** (for feeding and retracting of the cutting tool), **lubricator/coolant pump** (for delivering lubricating fluid to the area of cutting), **dust and chips removing unit**, **micro-stop** (for adjustment and control of drilling and countersinking depth), **backstop** (for limiting the amplitude of retraction), and **cycle counter** (for monitoring operation and control of process). Apart from the **micro-stop** and the **backstop** designated for manual adjustments and settings, all listed sub-systems are automated and require pneumatic power and pneumatic control. Naturally, these sub-systems require either their own dedicated source of power and air logic for control, or sources of power and control, if possible, to be shared with other sub-systems.

Figure 1 depicts an example for the most basic schematics of a conventional hand held automated drilling system.

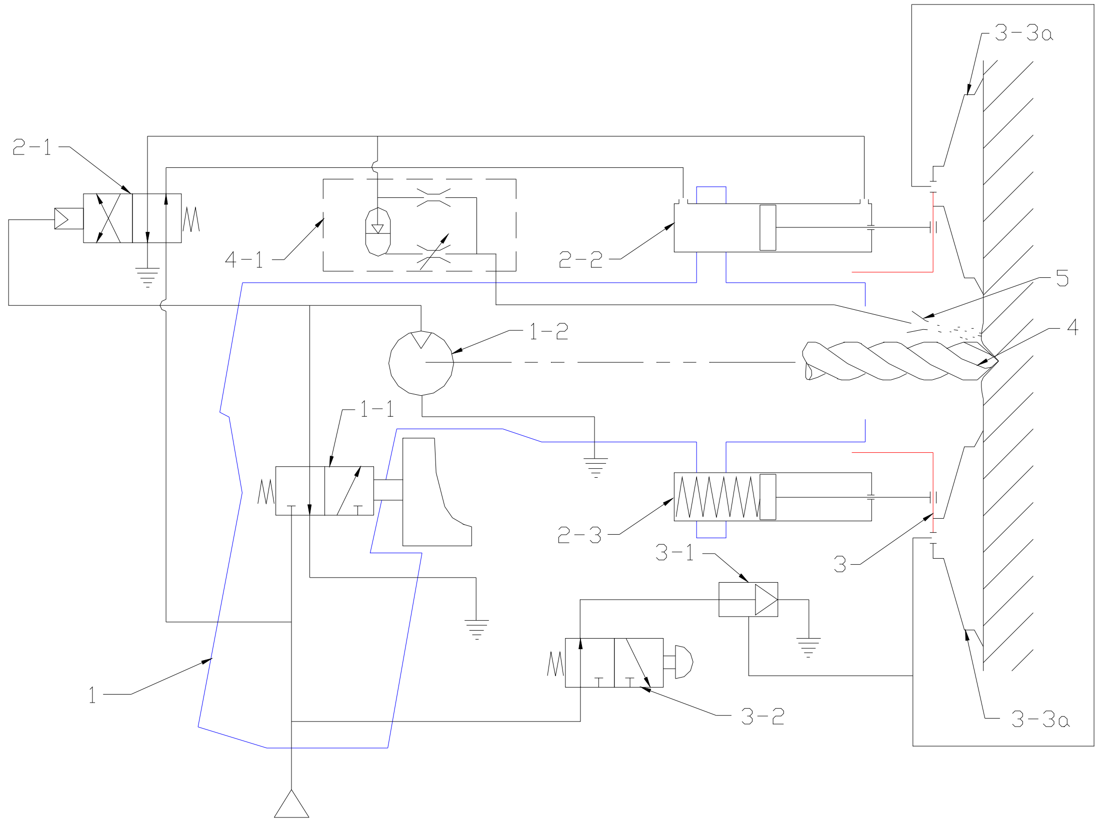

Figure 1

The system in Figure 1 incorporates a **main sub-system** 1-2, a **thrust unit,** that in turn includes one or (sometimes) two pneumatic cylinders 2-2 and a shock absorber 2-3, **anchor** 3 shown in red (utilizing vacuum suction principle of attachment), that slides parallel to the central line of the drill bit 4 (for attachment anchor 3 has two vacuum suction cups 3-3a and 3-3b mounted on it; vacuum generator 3-1 provides vacuum to feed both cups), **lubricator/coolant pump** 4-1 to deliver lubricating fluid to the end of drill bit 4 through nozzle 5. The entire system is mounted on the surface of the pistol shaped frame 1 shown in blue.

The power for the **main sub-system** 1-2 is provided through the bottom of the pistol frame and controlled by trigger 1-1. Just before the trigger 1-1 the input power is branched into a number of parallel lines supplying the **thrust unit**, the **anchor,** and the **lubricator/coolant pump**. Control signals operating the **thrust unit** cylinder 2-2 and the **lubricator/coolant pump** 4-1 are synchronized with the control of the **main sub-system** 1-2. In other words, when the trigger 1-1 is ON it provides a power flow to the motor 1-2 an therefore the rotation of the drill bit 4; simultaneously it powers **lubricator/coolant pump** 4-1 and sends a control signal to the pilot of valve 2-1 to operate the **thrust unit** and to start feeding of the drill bit 4. When the trigger 1-1 is OFF the power supply to **main sub-system** 1-2 and **lubricator/coolant pump** 4-1 is interrupted and their operation is terminated, valve 2-1 automatically switches to retract **thrust unit** cylinder 2-2 and the drill bit 4 into home position.

Power supply to the **anchor** 3 is normally open providing uninterrupted source of vacuum for the cups 3-3a and 3-3b thus enabling clamping to engage immediately as the cups seal to a drilling surface. Pushing the button of valve 3-2 disconnects the supply of power to vacuum generator allowing disengaging of the suction cups.

There are two commonly used types of drilling systems differentiated by designs of feeding:

- positive drive

  and

- power drive

The system shown in Figure 1 is the relatively new “power drive” system.

Although “positive drive” system is not the subject of interest to article, a brief description of it will outline the current general state of this technology, explain cons and pros of the “positive drive”, and be given to allow a better understanding of why there is a need for systems other than “power drive” and what their target specifications are.

“Positive drive” system is an older technology. It is also the benchmark in aircraft industry for producing consistent, precision, critical holes in mass quantities. Feeding of a drill bit in this system is arranged through coupling gears spun from the drill spindle. Such arrangement provides directly proportional relationship between the RPMs of the drill and the rate of feeding. When the load on the bit increases it causes a drop in the RPM of the spindle and a subsequent decrease of feed rate. When the load decreases the RPM rises and so does the feed rate. This function allows for maintaining of a constant thickness of material removed throughout the progress of drilling.

“Positive drive” system is powerful and, as of today, essential for drilling precision holes of larger diameters, requiring a substantial depth of drilling and for drilling through heavy layers composed of various materials. The negative aspects of the drills with “positive drive’ include: heavy weight, bulkiness, complexity of construction, and high cost. Due to the coupling gears used for enabling the feed function thrust vector can not be applied coaxially to the drill bit and in this system is arranged parallel to the central line of the drill bit. This causes a side-load on the drill bit. To compensate the inaccuracies due to the side-load, drill bushings have to be used, which, in turn, makes these drills bulky, impossible to operate in narrow spaces, and sometimes couses problems when drilling through surfaces of irregular geometry.

Yet another negative side of the drills with “positive drive” is that their construction effective delivery of cutting fluid to the drill bit is possible ONLY THROUGH THE SPINDLE and FUTHER THRU THE BODY OF THE DRILL BIT. Such form of cutting fluid delivery, although generally advantageous, complicates the system even further and as the only option left, becomes unjustifiably expensive and redundant in those applications where its advantages are irrelevant.

Arrival of the “power drive” systems, such as illustrated in Figure 1, was driven by the industry’s needs: first of all, because certain holes simply could not be produced by systems with “positive drives" and second, in order to minimize the redundancies and expenses associated with the use of the "positive drive" systems whenever their advantages were irrelevant. These needs were and still are partially covered by utilization of manually operated drills. Small, light, yet powerful pneumatic manually operated drills are commonly used for drilling non-critical holes, of smaller diameter and in narrow, difficult to reach places. But because they could not be used in operations demanding a high degree of accuracy, it led to a development of automated drilling systems with "power drive".

In "power drive" systems feeding takes place at constant velocity and at constant force applied to a drill bit. "Power dries" are designed so to dampen load fluctuations incurred by the cutting tool whenever they occur and thus to maintain constant thrust and velocity of the feed. Earlier versions of "power drive" systems, developed at Boeing Company, included three or four (seldom five) components comprising a **thrust unit** (ref. Figure 1). This version of **thrust unit** had one, two or three pneumatic cylinders 2-2, a shock absorber 2-3, and a pneumatically piloted valve 2-1 to control the unit.

In the absence of a pilot signal from the trigger 1-1, valve 2-1 remains in "home" position, providing pressure to the rear chamber of the cylinder 2-2 and keeping it fully extended. When trigger 1-1 is actuated, power is delivered to motor 1-2 causing the cutting tool 4 to spin, simultaneously switching valve 2-1, resulting in the rear chamber of the cylinder 2-2 being connected with exhaust and its front chamber being pressurized, thus causing the cylinder to retract. The retraction of the cylinder serves the feeding function. With the **anchor** 3 clamped to the object of drilling, retracting cylinder 2-2 pulls pistol shaped frame 1 (with the cutting tool 4 installed in it) toward the object of drilling The shock absorber 2-3 serves to dampen actuation of pneumatic cylinder 2-2 which other wise would be explosive and uncontrollable. The shock absorber also dampens fluctuations of the load occurring throughout the process of drilling.

Like the "positive drive" system, the earlier versions of "power drive" had a major draw back of inherent side-load due to the thrust being noncoaxial to the drill bit. Figure 2 illustrates the side-load generated by the early version "positive drive" system.

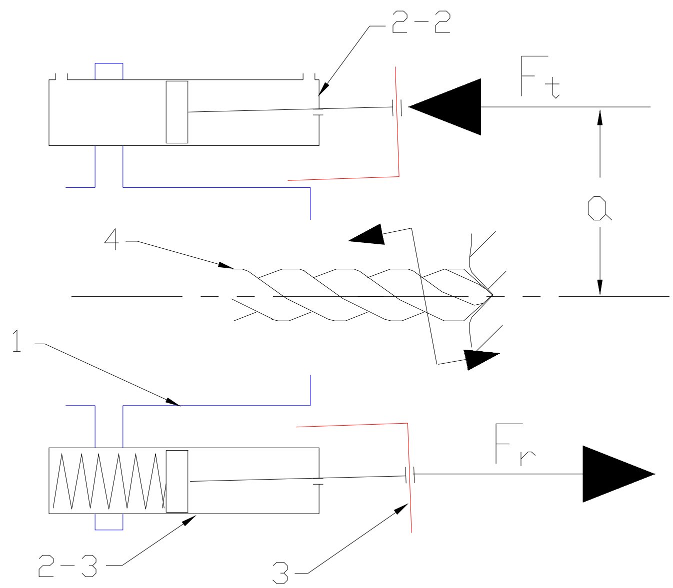

Figure 2

The point of application of the thrust force $\mathbf{F_t}$ that is generated by cylinder 2-2 is at an offset distance $\mathbf{a}$ to the centerline of cutting tool 4. This force produces a torque **M** applied to the drill bit 4.

$$\mathbf{M} = \mathbf{F_t} \times \mathbf{a},$$

Torque **M** causes inaccuracy of the holes and premature wear of the parts. It also results in conversion of a portion of the thrust $\mathbf{F_t}$ into a parasitic force of friction. This along presents a big problem, which requires some explanation.

One of the main reasons that necessitated the development of the drill system with "power drive" was for obtaining a compact tool for making holes in places where "positive drive" systems would not fit. This imposed strict dimensional limits on all utilized components, compactness of their mounting, and the layout of the entire system overall. Because of these dimensional constrains, bore size for cylinder 2-2 is limited to about 3/4in. Having cylinder 2-2 and shock absorber 2-3 mounted by brackets around drill bit 4 (as it was done on the original model) was already pushing the envelope. At 90PSI of working pressure a 3/4in bore cylinder could only produce 39.8lb of theoretical thrust – approximately 2.5 to 3 times short of the thrust level needed for efficient drilling. To lose any portion of this thrust to friction was already a major design flaw. A later model of this system was designed with two identical thrust cylinders positioned symmetrically at the opposite sides of drill bit. This allowed to somewhat compensate the side load and to double the thrust. However, it led to pushing the dimensional envelope even further and did not eliminate the presence of side-load entirely, because shock absorber 2-3 could not be mounted to produce dampening reaction $\mathbf{F_r}$ coaxial to thrust $\mathbf{F_t}$ (ref. Figure 2). Just like with thrust cylinder 2-2, the point of application of the dampening reaction $\mathbf{F_r}$

of the shock absorber was at some offset distance to the centerline of cutting tool 4 consequently producing side-load.

II. Modular Construction of Drilling Systems with "Power Drive" and Utilization of Hollow Rod Hy-P Cylinders in them.

In 2006 as a part of a big effort taken by The Boeing Company in creating and updating the processes and equipment for production of Boeing 787 Dreamliner significant steps were taken to overcome the earlier problems with drill systems equipped with "power drive". The pioneering novelty of Boeing's approach this time was to build a system having the thrust unit arranged coaxially with the cutting tool. To enable this design RB Hybro Dynamics, Inc. developed a first model of a Hy-P cylinder with a hollow rod.

Figure 3 depicts the conceptual schematics of the new hand held automated drilling system utilizing coaxial thrust from a hollow rod Hy-P cylinder.

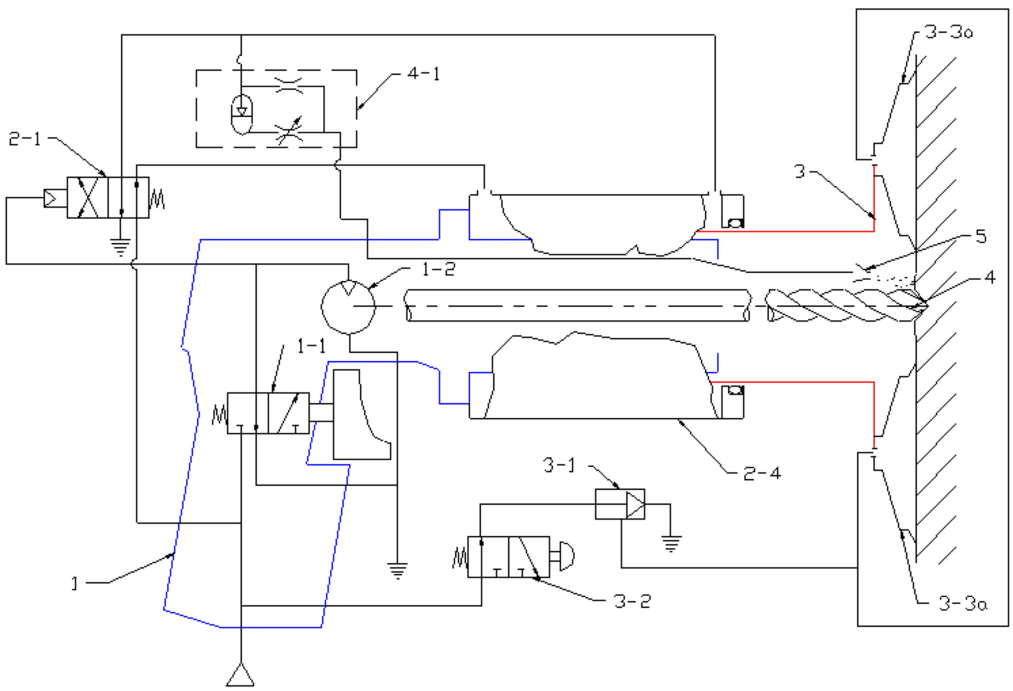

Figure 3

As shown in Figure 3, the hollow rod Hy-P cylinder 2-4 is placed coaxially with the drill bit 4 having the housing of the cylinder 2-4 mounted directly on the pistol shaped frame 1. This arrangement resolves the issue of size, making the entire system very compact without loosing much of active area of the bore responsible for generating thrust (112lb and 360lb of theoretical thrust at 90PSI). The use of a Hy-P cylinder combining the functions of thrust and dampening, made thrust force coaxial with dampening reaction and with the drill bit 4. Furthermore, it allowed to simplify the construction and to make the system even smaller thanks to elimination of the external components (thrust cylinders and shock absorber, mounting brackets, etc.)

In the new system rod 3 is designed to be also a base for mounting interchangeable anchoring modules. The latest development went beyond solving the immediate problems of the earlier systems. It yielded modularly constructed drilling systems that allow for optional quickly interchangeable sub-systems. In the instance of anchor modules there is a set of detachable anchors allowing different methods for clamping and securing the system to the objects of drilling and with different principles for guiding drill bits. These modules were designed so they could instantly replaced, utilizing the same footprint at the end of the cylinder rod.

Another example of modular construction introduced with the new system was the **control block** - the module incorporating all pneumatic logic responsible for the control of the whole system and its routing. Analogous to the anchor modules there are a number of different **control block** modules that can be mounted on the same footprint at the back to the cylinder and enable different set of control functions. Aside from the trigger 1-1 (see Figure 1) all the elements of pneumatic logic presented by schematics could be combined into a **control block** module. The selection of a particular **control block** module for a particular drilling system would, naturally, be dependent on how many sub-systems requiring pneumatic control are included into the system and what kind of control for each is intended.

The new system was designed also to have modular sub-systems that do not require pneumatic power and pneumatic control. An example of this would be the microstop module for accurate setting of drilling depth.

Since the beginning of the program in 2006 RB Hybro Dynamics has developed for Boeing two base models of Hy-P cylinders with hollow rod (Ø$1\frac{7}{8}$in and Ø$2\frac{5}{8}$in for main bore) with a variety of modular accessory sub-systems.

Figure 4a and Figure 4b show photographs of different views of the same original prototype for Ø$1\frac{7}{8}$in bore 1.5in stroke fully extended hollow rod cylinder with a mounted control block.

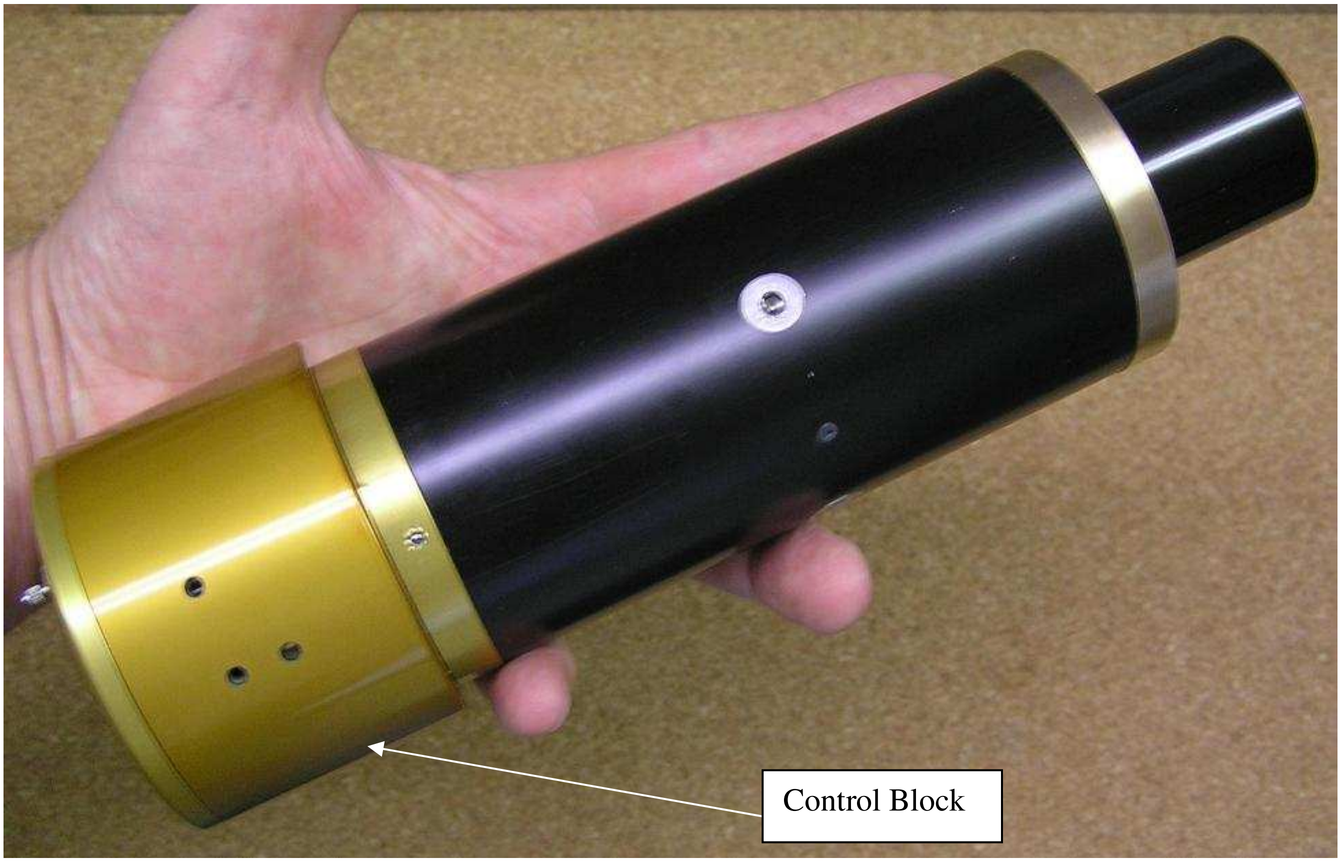

Figure 4a

Figure 4b

Figure 5 shows the sub-assembly of a Ø17/8in bore, 1.5in stroke hollow rod Hy-P cylinder with the control block mounted on the pistol frame. This is the same model and size cylinder as shown in Figure 4a and 4b and embodies a functional prototype based on the conceptual schematics of Figure 3 but without an anchor and a lubricator/coolant pump installed.

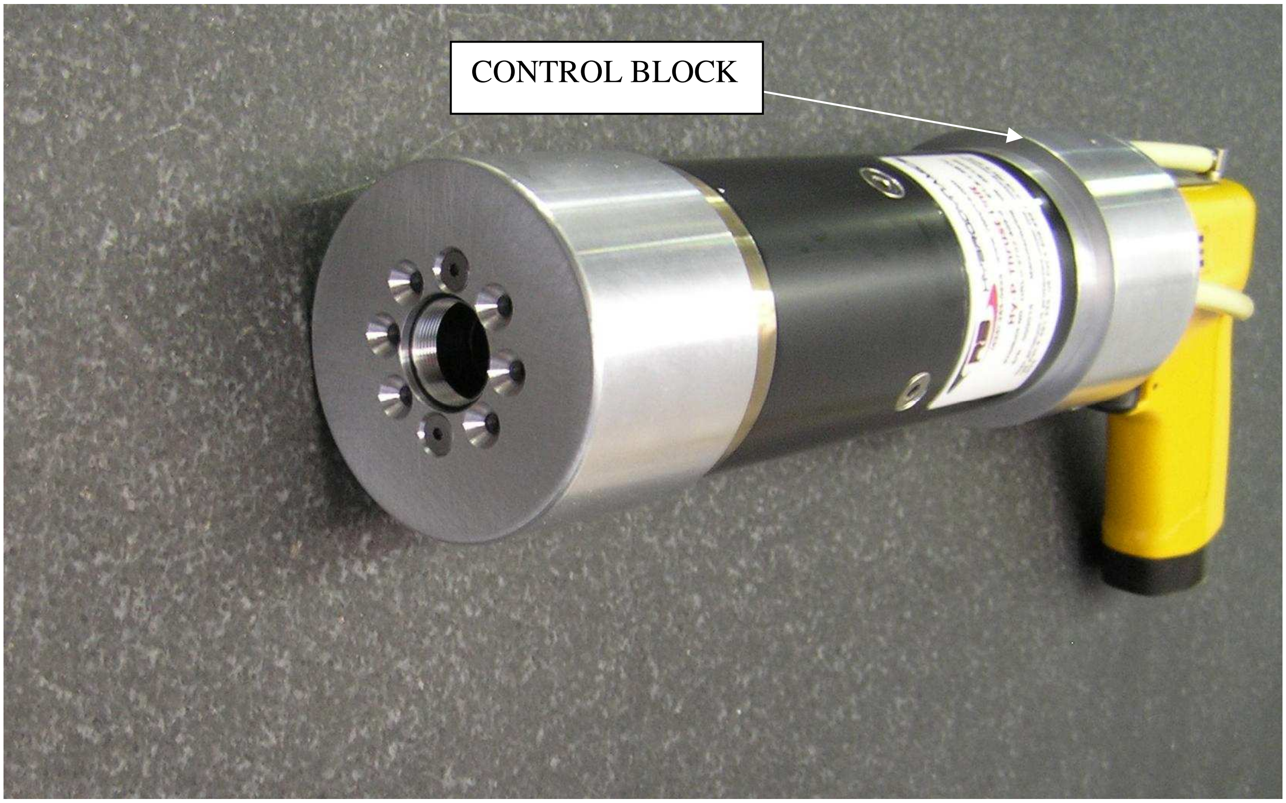

Figure 5

Although, at the level of prototyping such as illustrated in Figure 5 not all pneumatic lines are imbedded, most of the hoses for pneumatic communications of the new system, unlike in conventional systems, were arranged internally allowing to avoid evidential damage and adding to the compactness of the system. Particularly the set of long flexible tubes running all the way from the pistol frame to the footprint at the end of the cylinder rod to carry power, deliver lubricating fluid to the end of drill bits and transmit control signals to the anchors. It is the intention of RB Hybro Dynamics at the completion of the project to have all permanent communication lines imbedded and all the connections intended for connections of interchangeable modules to be either surface mount of with quick disconnects.

Figure 6 shows the first prototype of a power feed drilling system with hollow Hy-P cylinder that embodies complete schematics shown in Figure 3. This system, known under Boeing name MKATT-4, designed and built by RB Hybo Dynamics. Currently, several modifications of it with bore sizes 17/8in and 25/8in are undergoing testing at Boeing plant in Everett, Washington. So far the system with 17/8in bore has been quite favored due to the very compact and low weight design. Being small, it generates an impressive 110lb of coaxial thrust, carries 1.3HP motor and combines all essential functions outlined by the end users

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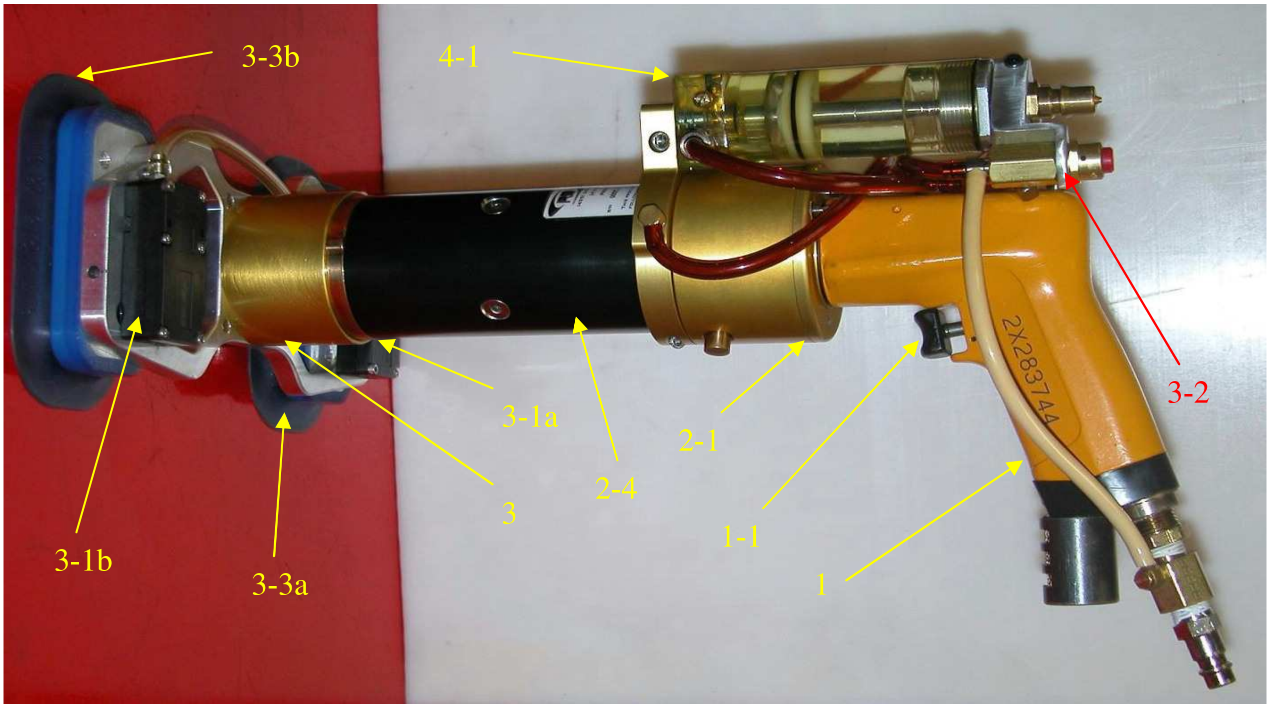

Figure 6

Apart from the engineering topics associated with Hy-P actuation there was always a topic of price. Since from the very beginning of this technology it was and remains high comparing to the common pneumatics. For this reason list of the most important customers of RB Hybo Dynamics predominantly consisted of major aircraft, space and military equipment manufacturers. The new hollow rod series as it is today is no different, however, recognizing potentially vast applications of the hollow rod cylinders in the general industry, in the near future the company is planning development of a much simpler version of hollow rod cylinders aiming at making hollow rod Hy-P actuation affordable to the general industry in applications like drill presses, milling machines, pull testers, etc.