<u>Fluid Connectors and a Hose For Every Application</u>

A major part of our international engineering project management work directly involves problem solving and systems designing-installation within hundreds of the world's applications of fluid power (hydraulics and pneumatics) energy transmission. Compressing a liquid or gas enables many machines and their components to lift heavy loads and to generate a reliable, sufficient force to create energy efficient capabilities that enable tough jobs to be handled with considerable time-savings ease. And the "arteries" that carry the fluids between pumps and motors, valves and accumulators, reservoirs and cylinders, filters and regulators often involve a piece of hose with fittings attached on each end of the line. We say *often*, due to the fact that metallic tubing can also in a few cases be utilized as well. However with applications' constraints involving vibration, sound dampening, flexing, routing, and corrosion, optimum systems designs continue to make a hose product the best method for carrying a compressed fluid compound. This remains quite possibly the most critical component of an entire fluid transmission system.

Within the fluid power industry, or better yet, call it the fluid conveyance engineering product lines offered throughout the world, there are literally hundreds, perhaps thousands, of different designs for hose construction, to handle virtually every possible task of moving a fluid (liquid or gas) from point A to point B. And the demands on superior product performance have never been greater as applications become more challenging, especially in terms of environmental contamination controls. Some hose styles handle only modest pressures, for compressed air pneumatic tool service (about 250 p.s.i.), or at the other end of the spectrum, 10,000 pounds per square inch (p.s.i.) for hydraulic tools and upwards of over 40,000 p.s.i. for applications involving water-jet cutting of concrete and metals forming.

Operating temperatures can range from frigid Arctic cold to extreme heat in steel mills and foundries. Today's multitude of hose compounds and their construction must also deal with an almost limitless selection of fluids: standard petroleum-based hydraulics, synthetics, biodegradable solutions, water-based, and fire resistant or even food grade compatible compounds.

In virtually every case, with only a handful of application-specific exceptions, each and every hose style will consist of three basic elements of its design and construction: an inner tube to transmit the fluid, a strength-bearing reinforcement, and a protective outer cover. Each layer is carefully specified, and engineered, performance tested to optimize the application success and maximize the product's durability over an extended period of time while in use.

The inner tube, typically made from synthetic rubber compounds or thermoplastics and composites, must be chemically compatible with the fluid contained within the hose. It must have what is called a controlled porosity to ensure that the tube does not become a sponge, inadvertently absorbing the fluid being conveyed along the line. Tube wall thickness is tightly controlled as well throughout the manufacturing process. Special compounds for the inner tube may be used to handle fire-resistant hydraulic fluids, called phosphate esters, for example, that would simply dissolve normal rubber tube compounds like sugar in coffee, or make the tube a sticky slurry of rubber. Further, the inner tube must withstand elevated temperatures that can actually bake the material hard, or cold temperatures that can render the hose useless and inflexible.

Reinforcement is the strength member of the construction that allows the product to safely handle both the pressure and flexing operating characteristics required of the hose when in use. It must tolerate widely fluctuating pressure spikes, inherent in fluid power systems at work to prevent premature hose bursts that could result in equipment damage or human injury if allowed to fail. The reinforcement determines the hose's actual working application rating; from relatively simple textile braided reinforcement for low pressure applications, to multiple layers of steel wire braid or steel – even Kevlar – spiral wrapped construction in the much higher pressure designs. A layer or membrane, of rubber is laid in between each layer of reinforcement, to provide adhesion of each layer, as well as delivering a slight shock absorption or what might be called a metal fatigue-resistance to the adjoining metal layers, in particular while under pressure and flexing conditions.

Steel reinforced hose products – and make no mistake, these are highly engineered products, not merely garden hoses in our backyards – consist of two primary categories, as mentioned. They are a combination of precise-angle braided lines or a side-by-side, tightly packed spiral-wrapped, opposing angles paired in multiples of two-times (2, 4, 6, 8), in a layering construction. The normal maximum working pressure limits for wire braided technology run about 5,000 to 6,000 p.s.i. whereas the pressure capacities for spiral reinforcement construction range from a couple thousand p.s.i. to well over 60,000 p.s.i. The design tolerances and fittings attachment, especially at those system pressure levels, become extremely complicated, with rigorous proof-testing done for every manufactured hose assembly to guarantee zero failure.

The spiral reinforcement construction is usually thought to bring more flexibility endurance to a hose while under higher hydraulic system pressures. The braided construction tends to work against each wire end and each layer, creating a cutting effect in extreme applications, where considerable flexing takes place. A spiral design packs the reinforcement in such a way that is conducive to rapid impulse conditions, where constant flexing also can fatigue other hose constructions. As fluid powers systems continue to become increasingly sophisticated, more is being asked of a hose to respond to higher pressures, more flexing, tighter bending installations, smaller envelope diameter sizes, and an ever-changing array of fluids used.

And finally, there is some kind of cover material that completes the hose wall construction. The cover has several primary functions. The manufacturer's name, part number/style, cure date of fabrication, pressure rating, and other trademark requirements can be found on the hose's layline. From this we can ascertain the hose product's suitability to application temperatures and the "freshness" of the rubber materials, for example, as in many cases aging degradation can be a factor in a hose installation. The hose cover protects the tube and reinforcement from heat, chemical attack, abrasion, even corrosion. It also provides ambient structural integrity in terms of ozone resistance, ultraviolet light, and in some cases, and element of increased kink resistance.

Over the past 30 years, I have noticed that pressure capacities mean different things to different people, end users and operating systems designers alike. High pressure might be best categorized as a range from approximately 3,000-5,000 p.s.i., with notable exceptions of course. Medium pressure applications usually fall within the range of 3,000 to 1,500/maybe 1,000 p.s.i. While low pressure might be referred to as anything under 1,000 p.s.i. and can even be reduced to pneumatic systems under 500 p.s.i. The ultra high pressure applications are over the 10,000 p.s.i. mark, and often are called ultra high pressure even above the 6,000 p.s.i. threshold. Quite possibly you get the general idea at this point in the paper's discussion. High pressure hoses can be a 2-wire braid construction, or even lower-rated 4-spiral steel wire designs. Medium pressure hose styles are designed with multiple layers of both braided steel wire and textile reinforcement, while low pressure styles almost always have a textile braid reinforcement design. Even special application air conditioning hoses, transmitting Freon or R134a refrigerant hose products have been developed with textile reinforcement and barrier layers of Mylar or bonded shielded layers to inhibit the effusion of the aggressive refrigerant compounds that tend to migrate through the hose walls. With the passage of time, not only are there an increasing variety of special use hoses, but also many hybrids and new standards to accompany newly developed hose designs, becoming a distant memory from what used to be called a normal hose product, and normal construction.

In the earlier days of hose design and construction, one might say that with an increase in overall diameter of a hose, the pressure rating typically was reduced. On the other hand, the smaller the hose size, the higher the pressure rating. However that too, has changed dramatically with so many new designs and constant-pressure hybrid constructions.

Other application parameters have dictated that newer breeds of design and construction be brought to the marketplace. Hybrids offering improved flexibility characteristics, much tighter bending radius attributes, weight restrictions, non-conductivity to electrical current, and environmentally friendly fluids, even de-ionized water coolant applications, continue to create needs for a steady stream of hose products.

In the majority of cases, S.A.E. (Society of Automotive Engineers) has had a long history of providing the basis for developing and governing standards for hose construction and design specifications. Called a 100R design, these somewhat simplistic references compile most hoses used around the world today into neatly defined categories, which continue to serve the systems design engineering professions well. But with time, and the introduction of many new global competitors, new standards for recognition, and the endless list of hybrid construction technologies, the 100R designations have continued to grow in number. The ultimate goal has always been to bring some kind of uniformity, dimensional understanding, and quality assurance to multiple manufacturers of hoses, covering an enormous range of machinery field applications. SAE Standard J517 provides a general set of specifications including dimensional and overall testing-performance for the 100R Series already mentioned.

Throughout the global marketplace, other standards have evolved over time as well. They include a European Norm/Standard (EN), Deutsche Industrie Norm (commonly called DIN), and the International Standards Organization (ISO). We also have Japanese standards (JIS), Korean and Chinese standards from earlier years of product development. And they can vary widely from SAE, along with many government standards especially for safety compliance issues in mine operations – MSHA – Mine Safety and Health Administration and the American Department of Transportation (DOT) Federal Motor Vehicle Safety Standards, referred to FMVSS.

Hybrid designs, those that do not precisely fit comfortably into a given 100R category, remain on the increase, due to very specific application requirements. A number of manufacturers have developed – often times at the request of a large OEM customer or industry segment – hose styles that far exceed the performance and construction characteristics of SAE specifications. The end-user benefits may involve higher pressures for niche hydraulic applications, higher temperature capabilities, the enhanced flexibility already discussed for unusually confining hose routing circumstances, even a bend radius that can be less than one-half of what is prescribed in an SAE standard. Hose styles have been given brand name recognition such as *Hi-Pac*, *Mega-Flex*, and *Compact* as examples. And this product development continues with global producers.

One of the other requirements in developing any hose involves its pressurized impulse service life. Manufacturers boast about cycle life testing of over 1,000,000 pressure impulses, to effectively determine the extended life span of a hose design. And an elevated temperature of in excess of 200-250 degrees Fahrenheit (over 100 degrees Celsius) is a benchmark to further prematurely age the hose in life-cycle testing. An SAE standard of 200,000 impulse cycles is typical for meeting certain design criteria. Other products may fall into impulse cycle testing cycle goals of 500,000 to 600,000 surges of impulse pressure. A square wave requirement for holding a pressure for an intermittent amount of time can also become part of the hose's advertised test strength qualities. This is a common machinery OEM testing requirement. The obvious reference to such extended service life is for difficult to access plumbing in a hydraulic system, total extended service life, less equipment downtime to equate to reduced costs, and no fluid spillage contamination.

A brief overview of the SAE standards might shed some light on just how these standards are comprised and illustrate the tremendous diversity in hose materials and construction available in the global markets.

SAE 100R1

Has a 1-wire braided, high tensile steel wire construction, built around an oil resistant (nitrile rubber) inner tube, all enclosed within an oil resistant outer carcass, or cover. The cover is also weather, ozone, and UV-resistant, with a common NBR or blended NBR-PVC compound material. It is commonly classified as medium pressure hose. A cover designated as AT means a thin cover whereupon the outer cover is not skived (meaning to remove the cover for fitting attachment), simply place an appropriate-compatible fitting over the hose and compress the fitting onto the hose for pressure-holding durability. A Type A cover construction usually requires some removal of the cover material in the area to be compressed by the fitting attachment. The primary key is to have any hose fitting actually bite into (not breaking however) its wire/textile reinforcement to secure the hose and fitting combination when placed into pressurized service. Virtually every style of hose and fitting has a highly engineered, precise set combination, compression (crimp) setting in an assembly machine, with the understanding that specific hoses go together with certain fittings, as specified by the manufacturer. A Type S is the same as AT, with working pressures in compliance with ISO 436-1, Type 1SN.

SAE 100R2

This hose product is usually designated as a high pressure kind of hose, and remains the proverbial workhorse of the fluid power industry. It consists of two distinct and separate layers of high tensile steel wire braided construction reinforcement. It has an inner tube of course, the pair of braided layers, and a rubber cover. Type A requires skiving (an old term for removing the cover in the fitting area as mentioned). The procedure for skiving a hose has been around for a long time, and a wide variety of hand tools are utilized to precisely remove the outer cover. However, most fluid connectors design engineers and plumbing installation technician experts contend that the days of using an unusually thick hose cover have passed by – the heavy carcass was to prevent abrasion-reinforcement exposure – but proper routing and protective sleeve materials (heavy nylon, steel coil wrap) almost always prevent unnecessary wearing of the outer cover to the point of catastrophic hose assembly failure.

Skiving was always a messy, time consuming process, and the name itself harkens back to a very primitive time in hose & fittings. The extra cost and weight of extra-thick hose covers has also made this construction prohibitive except in only the most demanding of hose application practices. Many hose manufacturing companies now utilize no-skive or TTC (through-the-cover) fittings with deep annular rings that in fact penetrate the cover and bite into the reinforcement with proper gripping power under fluid dynamic pressure and the cover acts as a seal.

Neoprene rubber (similar to a person's shoe heel) has been determined to also benefit outer cover durability, with improved hardness and material abrasion resistance, to some degree.

SAE100R3

This hose product generally has two layers of textile braid construction, and is most widely used in what we commonly refer to as low pressure applications, with standard petroleum oils, antifreeze, water, or general fluid transfer applications.

SAE100R4

This product is simply referred to as full-vacuum suction hose, due to its construction which consists of a helical support coil, several plies of textile fiber reinforcement for some element of strength capability, and kink resistance. Many styles of hose do not sustain a vacuum service capability, perhaps only a partial suction capacity, which might otherwise cause the hose wall to collapse and close upon itself.

SAE100R5

Often called a tubing replacement hose product, this style seems to have been around forever. It is dimensionally slightly different than the other styles discussed so far. Its origins date back to a time when flexible rubber hose was initially being introduced into the transportation industry to replace rigid, and vibration-corrosion prone metallic tubing. Any hose has a "dash number-size" that equates with one-sixteenth (1/16) measurements, for a *full-bore* inside diameter. Dash four (-4) means basically 4/16 or quarter-inch I.D. Dash 8 is half-inch, dash sixteen is 16/16 or a one-inch inner diameter. R5 hose is a multiple layer combination of textile braid and steel wire braid, often found in truck and off-highway vehicle applications, engine hose, with liquid rubber-impregnated layers and its fiber cover, to prevent moisture migration or weathering degradation (mildew).

SAE100R6

It is a largely defunct hose product, with one braided layer of fabric or a spiral wrap yarn construction, used for very low pressure applications – hybrids have eliminated its use.

SAE100R7-SAE 100R8

This is a pair of medium (R7) and high (R8) pressure hose products (comparable to 1 or 2-wire applications, respectively), except for their completely thermoplastic constructions and fabric braided reinforcement compounds. They are lightweight, easy to assemble with crimp (or swaged), or reusable thread-on fittings, and come in both standard black and orange non-conductive (for aerial life applications, for example) hydraulic-general purpose fluid conveyance applications where light weight and easy-to-handle and lifting (hydraulic tools, "jaws of life," hydraulic power tools) are critical to the operator. The specific thermoplastic materials may vary, but typical of the inner tube might be a Hytrel polyester and a urethane-based outer cover – Kevlar and polyester make up the inner reinforcement layers. Their popularity has been on the rise since about the late 1980s and into the mid-1990s, with hundreds of hybrid variations now available in global markets.

SAE100R9 (4-light spiral), SAE100R10 (4-heavy spiral), SAE100R11 (4-spiral)

We no longer see these hoses (old "friends") much in fluid power applications anymore, given the tremendous rise in advanced wire spiral wrap reinforcement technologies as well as the severity of high and very high pressure applications on the continuous rise. The difference between R9 and R10 was mainly the thickness of each strand of steel wire. Caterpillar Tractor even made their own spiral hoses used on their heavy off-highway construction and mining machinery, and had their own designation for CAT Hose, too. However, with increasing emphasis on higher pressure ratings and greater flexibility characteristics, hybrid compounding, and unique extra-durable cover construction designs, the family within this category has for the most part gone that way of old R6 styles, replaced by a much better array of incredible hose products. You should know though that these products are still available with some hose manufacturers, who have a few customers who still specify certain designated hose constructions.

SAE100R12

This remains yet another of what we tend to call the workhorse hose products within any manufacturer's breadth of product lines. It is a 4-spiral wire wrap reinforcement construction, with synthetic rubber inner tube, and rubber cover. The tube us usually nitrile rubber, and the outer cover constructions now come in a large variety of tough-cover designations, where ultra-critical abrasion resistance is the norm in hydraulic very high pressure field applications. They can carry an ISO 3862-1 and EN 856 designation. MSHA approvals and higher temperature (up to 257 F./125 C.) ratings will also accompany this product line. Besides super tough cover compounding, its claim to fame is in greater flexing characteristics at high impulse surge pressure cycles.

SAE100R13

This is the multiple-vendors' great-grandson of Caterpillar's original 6-spiral hose reinforcement construction for very high pressure, extreme flexing applications, in construction and mining machinery. It also carries now and ISO 3862-1 and EN 856 designation today. It is a constant pressure 5,000 p.s.i. service product, for some of the harshest hydraulic applications. In particular where easy and convenient field hose assembly replacement is almost impossible, and equipment downtime can be disastrous. Petroleum and water-based hydraulic fluids make up its primary usage.

SAE100R14 (Type A)

Now we detour for a few moments and draw our attention to PTFE (Teflon – called **p**oly**t**etra**f**luor**e**thylene – inner tube) hoses, with regard to this specification. Pressures can range from about 1,000 p.s.i. in larger sizes (1-inch diameter), to the range of 3,000 p.s.i. in a quarter-inch hose product. The stainless steel wire braided reinforcement also doubles as a corrosion-resistant cover. It handles petroleum, synthetic, and water-based hydraulic fluids, with an advantage of higher temperature capabilities (-100F. and up to 450F.) in a wider range, excellent fluid compatibility due to the Teflon core, lightweight, and is also available in a Type B non-conductive, static electricity-dissipative inner tube construction, made with impregnated carbon black. Applications are as diverse as: coolant lines, steam lines, paints & coatings, adhesive dispensing, compressed air/gasses, medical gasses, and food processing machinery installation plumbing.

SAE100R15

Now things really become interesting, with our return to reviewing rubber hose, but at this point in our paper, we examine the super-high-pressure hydraulics realm of today's more exotic (for lack of a better way to put it…) extremely high pressure fluid handling hose products. At this specification juncture, we are looking at applications calling for a 6-spiral wire wrap reinforcement, which can handle with ease, pressures at a constant p.s.i. rating of 6,000 pounds per square inch – virtually unheard of when I started into the fluid power industry at the end of the 1970s. There is even an 8,000 p.s.i., -12 & -16 size 6-spiral construction, but not enveloped in the R15 specification.

SAE100R16

This hose was originally one of the first "hybrid designs, without an SAE spec., with applications requiring the very tight bend radius installation and flexing parameters that we covered earlier in talking about *Hi-Pac* and *Compact* brand name hose styles. Their two decades of popularity in field use created the need for their own SAE family tree. To over-simplify this explanation, these 2-wire braid reinforced products developed a sales campaign in which they talked about the pressure holding capabilities of a 2-wire hose, with the routing-flexing (new reinforcement designs) characteristics of a 1-wire hose, and accompanying lighter weight, and less expense, in some cases.

SAE100R17

This designation further advanced the fluid power industry's embrace of more hybrid construction designs and field service attributes long desired by both OEM engineers and end users. This is a high pressure hose with either one or two wire braid layers of steel reinforcement construction, but the feature is that of a constant working pressure, no matter what the size of the hose product in use, normally at 3,000 p.s.i. across all sizes.

SAE100R18

This is another of the fluid power industry's thermoplastic hose constructions. Its many uses cover the range of synthetics, petroleum, and water-based hydraulic fluids, but in a slightly narrower temperature range (increased low-temp. use) of -70F. to 212F. (-57C. to 100C.) with a vacuum rating of (theoretical full vacuum) of 28 Hg. service. The inner tube is thermoplastic construction (polyester), 1-braid fiber reinforcement, and polyester-blend cover, in both regular and non-conductive (orange color) that meets SAE J517 for less than 50 micro-amps leakage under 75,000 volts per foot. Cold climates, enhanced kink resistance, over-the-sheave pulley applications (constant flexing-bending, in the cold) make it superior to older-style 100R7 products. Yet another hybrid, with the 3,000 p.s.i. constant pressure (in all sizes) feature!

SAE100R19

And finally, our tutorial on fluid conveyance hose products concludes with another relatively new SAE specification to cater to the continuously growing stable of hose options available to any OEM and every end user on the planet. This hose also has the constant pressure rating badge, but at 4,000 p.s.i for all available sizes. The strength reinforcement consists of either a 1-wire or 2-wire braid construction, with the normal calendar layer or cushion-protective rubber wrap layer in between the inner tube and wire reinforcement, to create less abrasion in the tube and to give improved adhesion of the braided wire to the tube, a common design in just about every rubber hose product.

Conclusion

As you might imagine, there are an almost unlimited number of hoses and related fittings products available in the international marketplace today. They cover not only hydraulic and pneumatic (compressed air) applications, but also general fluid transfer, welding and oxygen-acetylene flame cutting, marine engines, the transportation industry, railroads, laboratory environments, and a host of so many other end uses. The hose products' physical constructions, various specifications, materials for construction, along with a limitless internal & external/ambient temperature capability, fluid-chemical compatibility difference, do indeed make the proper selection of a flexible line critically important. Some people spend their entire careers just learning about this amazingly diverse technology and the accompanying engineering know-how that must go into every product decision. Part of our job is to help you do just that.