**SPECIAL REPORT — Hose Manufacturing**

# Innovation in hydraulic hose, couplings industry

**By Andrew Dittmer**
**and Cindy Cookson**
Gates Industrial Products

## Executive summary

It's an exciting time to be a part of the hydraulics industry. Advancements in materials and processing technologies are enabling hose performance that goes well beyond dated standards and delivers exceptional value to customers and system designers. However, these values are only realized if the hose and coupling are designed to work together and properly assembled.

Innovations in hose design and crimper machines have come a long way and are providing the critical elements needed for integration. The benefits, including time, resource and cost savings, will be realized across many industries where the quality of industrial equipment operations makes all the difference.

We are living in an age of innovation for the hydraulic hose and coupling industry. Manufacturers continue to explore new technologies to accommodate increased market demands and the evolving needs of applications.

Equipment in markets like construction and agriculture are demanding tougher industry standards for more compact hydraulic systems with increased power and performance. Manufacturers of hydraulic hose and couplings are rising to the occasion by leveraging material science to deliver innovative products led by advancements in composite rubber elastomer, manufacturing processes and tools for hydraulic assembly applications. The results are time and resource savings while increasing performance and reducing downtime.

**TECHNICAL NOTEBOOK**
Edited by John Dick

### Global viewpoint

Market requirements for hydraulics continue to evolve, driven by both higher performance requirements of innovative systems as well as the globalization of equipment platforms within industries like construction and agriculture.

Historically, engineering societies created standards for hydraulic hose and couplings that were primarily regionally focused; for example, the Society of Automotive Engineers for North America, German Institute for Standardization (DIN) for many parts of Europe and Japanese Industrial Standards for areas of Asia.

In the past, there was variation between these regional standards for performance measures such as working pressure, burst pressure, hose dimensions and temperature range, to name a few. This not only created confusion for many customers—especially when designing a product for global use—but added complexity for hydraulic manufacturers tasked with the development of multiple unique yet similar products.

Thankfully, standards organizations have aligned the requirements such that now a single hydraulic hose can often successfully meet multiple regional standards. Furthermore, organizations such as the International Organization for Standardization (ISO) have issued hydraulic hose standards like ISO 18752, which are truly global in scope.

### Shift in requirements

The ISO 18752 standard shifted away from defining hydraulic hoses by construction, instead focusing on hose performance. Traditional hydraulic hose standards defined by SAE, DIN or JIS focused more on hose construction attributes (spiral or braid reinforcement, number of reinforcement layers, dimensions, etc.).

The standard instead specifies hoses by constant pressure ratings, operating temperatures and number of impulse cycles for several varying levels of performance—from 200,000 all the way up to 1 million impulse test cycles. This simplifies the hose selection process for design engineers and allows the hydraulic system to be optimized for duty cycles from light to severe duty. By not defining rigid material or construction requirements, ISO 18752 also frees up hose manufacturers to be more innovative in creating design solutions with new materials and processes while still matching or exceeding the defined performance levels.

At first glance all hydraulic hoses may look similar, but these hoses are highly engineered elastomer composites made to exact specifications. The main components of all hoses include a tube to carry the fluid, reinforcement for strength and a cover to protect both (**Fig. 2**).

Hose materials must be carefully selected and designed to work together to balance working pressures and flexibility. Both materials science and process innovations in recent years have enabled hose designers to elevate hose performance to new heights.

Tube elastomers can now handle chemical compatibility for a wider variety of petroleum-based and synthetic hydraulic fluids at higher temperatures of up to 300°F. The wire braid reinforcement method leverages new, high-strength steels and advanced braiding methods to produce a higher density wire pack for greatly increased hydraulics system pressures in the same hose size. Modern hose cover materials leverage advanced compounding technologies and materials science to enhance abrasion and temperature resistance without sacrificing ozone resistance, flexibility, or any other practical performance parameters.

In addition to the hose, couplings have benefited from advanced metallurgical engineering and plating processes to increase corrosion resistance more than 1,000 percent on industry standard salt spray tests using more environmentally friendly materials (**Fig. 3**).

These innovations in materials science result in a modern hydraulic hose assembly that greatly outperforms previous generations.

The application advantages and engineering performance improvements can be demonstrated by comparing a "modern" -16 size, single wire braided hose to a "conventional" -16 SAE J517 100R2 specification hose. In this comparison, the modern hose has significant advantages in the areas of space requirements, hose routings, pressure drops, safety and weight.

## The authors

Dittmer Cookson

Andrew Dittmer is a graduate of Colorado State University with a degree in mechanical engineering. His 23-year career at Gates has included a variety of positions, serving both industrial distributors and original equipment customers in the agriculture and construction markets.

Cindy Cookson is a 15-year rubber industry veteran. After completing engineering degrees at Kansas State University and North Carolina State University, she spent 10 years in the tire industry and the last five as engineering manager and product line director at Gates. She serves on the executive board of the Colorado Advanced Manufacturing Association.

### Hose design

*Outside diameter – Cross sectional space*

Modern hoses have a smaller outside diameter allowing for a more compact design, and the smaller hose fits more easily on existing equipment for quicker installation. Engineers who are designing new hydraulic systems can use less space with a modern hose, which can reduce the overall machine size or free up valuable real estate to accommodate other components. **Fig. 4** shows the 6.6 percent smaller outside diameter and the 12.9 percent smaller cross sectional area for the -16 modern hose compared to the -16 SAE 100R2 hose.

Hose-cable tracks are often used on more complex machines to route and guide multiple longer hoses and electric lines. The smaller cross section of modern hoses take up less space in the track, which is beneficial for adding additional items

**Fig. 1: Demanding applications in agriculture industry drive hydraulic development.**

**Fig. 2: Construction components of hydraulic hose.**

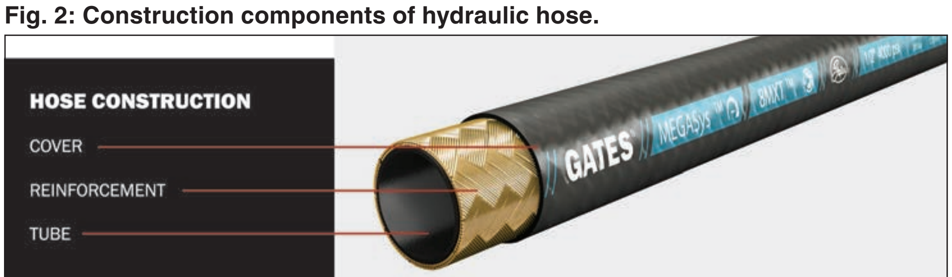
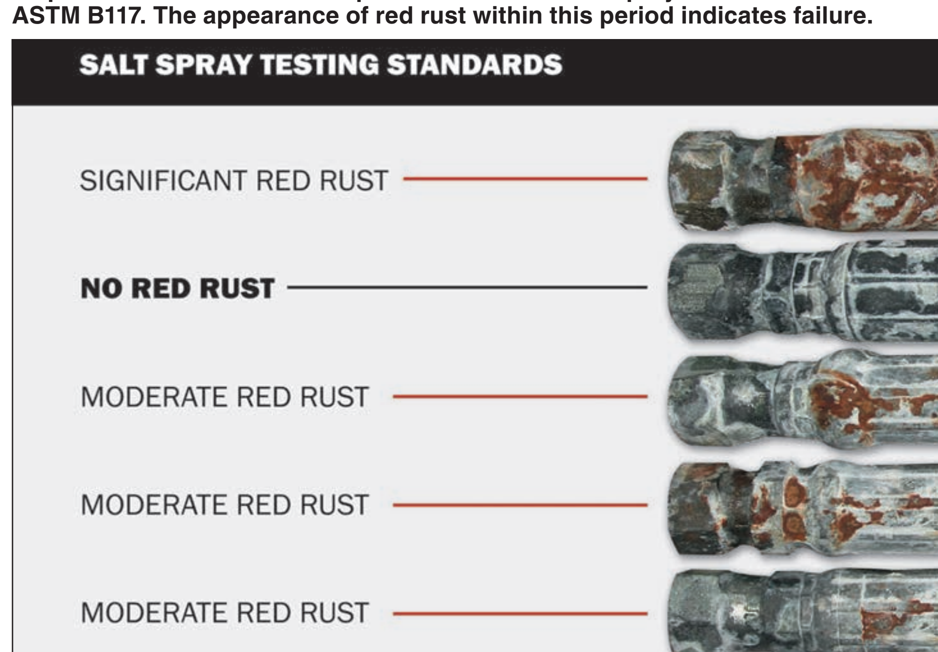



**Fig. 3: The SAE J516 standard for hydraulic fittings specifies that fittings shall be plated with a material that passes a 72-hour salt spray test in accordance with ASTM B117. The appearance of red rust within this period indicates failure.**



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without having to redesign existing tracks or possibly redesigning with a smaller track for additional machine space and weight savings. **Fig. 5** compares the 11.7 percent track area savings for three -16 size hoses with 2 millimeter clearances between components. For comparison, the smaller, red-colored modern track and hoses are superimposed over the larger, black-colored 100R2 hoses and track.

*Minimum bend radius – Hose routing area and pressure drop*

The advanced materials design of modern hoses improves flexibility, allowing for a much tighter minimum bend radius. For the example -16 size hoses shown in **Fig. 6A and 6B**, the modern hose MBR of 152 millimeters is half the MBR required by the 100R2 hose. The smaller MBR allows engineers to use tighter hose routings and provides greater design flexibility for placing other components such as pumps, valves and cylinders to achieve the most compact overall design possible.

The hose routing length of 1,550 millimeters for the larger MBR 100R2 hose can be reduced in length to just 425 millimeters with the smaller MBR modern hose for a 72 percent hose length difference. Comparing the square routing area and cubic volume (using hose diameter) shows more than 70 percent savings in space required to fit the modern hose, compared to the conventional 100R2 hose (**Fig. 6A and 6B**).

The shorter hose length enabled by smaller MBR reduces pressure drop and increases fluid flow. Computer modeling of the -16 hose routes demonstrates over 50 percent less pressure drop compared to the -16 100R2 hose. Improved flow rate creates less pressure drop and heat generation, resulting in improved system performance. This may allow the designer to re-engineer hydraulic pumps and other components for additional system savings (**Fig. 7**).

*Force to bend – Installation, ergonomics and safety*

The advanced materials, construction and processing used to manufacture a modern hose result in an extremely flexible hose with minimal force required to bend. The -16 modern hose takes only 3.3 kilograms of force to bend compared to the 10.3 kilograms of force required to bend the -16 100R2 hose to the same diameter.

This improved flexibility makes hose installation much easier, especially in compact hose routing designs. This reduces the time and labor cost required to install hose on the production line or during field replacements. Timed installation trials show the modern hose taking 50 percent of the time or less to route. Better ergonomics also make it safer for all installers, reducing the risk for injuries.

*Hose and fluid weight – Lighter systems, fuel economy, fluid reservoir and cooling*

The advanced, modern hose is significantly lighter weight compared to conventional hose designs. This makes moving and installing hose assemblies much easier. OSHA recommends a single person lift a maximum of 23 kilograms, so the lighter weight modern hose may negate the requirement for two people to lift longer and heavier hose assemblies. The -16 modern hose is 30.1 percent lighter weight than the -16 100R2 hose per unit of length.

The modern hose is not only lighter in unit weight, but also offers further weight savings potential. As demonstrated above with the hose routing example, the tighter MBR for modern hoses can reduce the hose length required. This not only reduces the cost of the hose assembly, but it also reduces the weight of the hose itself plus the fluid contained in the hose, allowing a 77 percent total weight savings from the hose and fluid.

When applied to multiple assemblies on one machine, the overall reduced hydraulic fluid volume may improve cooling or possibly allow a smaller fluid reservoir to be used, saving additional weight and space. Lighter-weight, modern hoses help design engineers meet overall machine weight goals for shipping requirements, improved fuel economy and other design goals (**Fig. 8**).

*Impulse cycles – Durability and replacements*

The field performance of hydraulic hose assemblies can vary depending on actual fluids, pressures, temperatures, duty cycles, load spikes, abrasion, etc. Industry standards such as SAE J517 define laboratory impulse tests to assist in comparing the relative performance and durability of braided hydraulic hoses. These standards specify a minimum hose performance level of 200,000 impulse cycles. The premium performance of modern hoses has been tested to provide 600,000 impulse cycles or more. At three times the industry standard, these products meet the demanding application performance requirements and keep machines running to avoid downtime costs (**Fig. 9**).

*Multiple assemblies – Overall machine savings*

The examples show the potential benefits and savings of designing with modern hose for just a single hydraulic assembly. Large pieces of equipment may have anywhere from 10 to 30 or more hose assemblies per machine. **Fig. 10** shows the overall estimated savings potential when converting from conventional 100R2 hose to a modern hose for a machine with 15 hose assemblies.

Combining the space, weight, flexibility and durability improvements of modern

*See* **Hose**, *page 16*

**Fig. 4: Space reduction from reduced hose outside diameter.**

| -16 SIZE HOSE | 100R2 | MODERN | DIFFERENCE | REDUCTION |
|---|---|---|---|---|
| O.D. (mm) | 37.6 | 35.1 | -2.5 | -7% |
| CROSS SECTIONAL HOSE AREA (mm²) | 1,110 | 968 | -143 | -13% |
| TRACK AREA (mm²) | 5,148 | 4,545 | -603 | -12% |
| CIRCUMFERENCE - CLAMPING (mm²) | 118.1 | 110.3 | -7.9 | -7% |

**Fig. 5: Reduced size of hose and required guide track.**

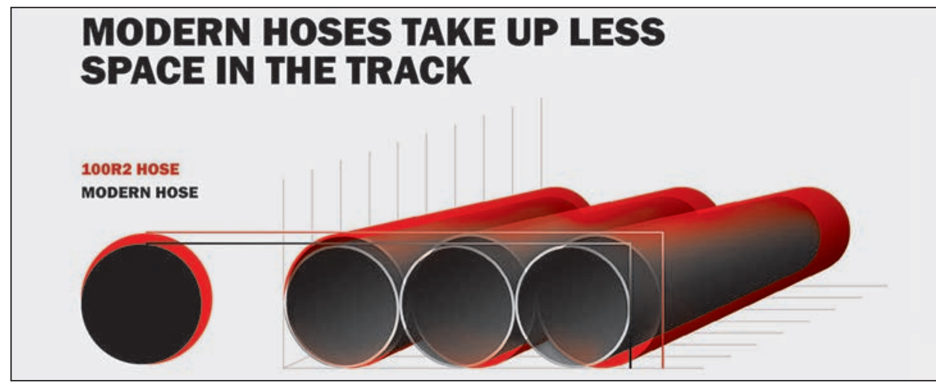
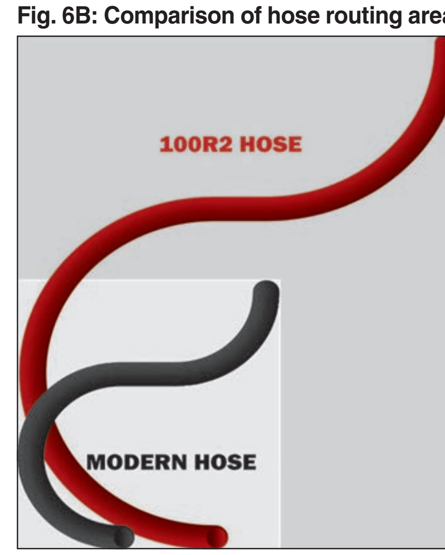



**Fig. 6A: Comparison for hose routing and pressure drop.**

| -16 SIZE HOSE | 100R2 | MODERN | DIFFERENCE | REDUCTION |
|---|---|---|---|---|
| MINIMUM BEND RADIUS (mm) | 305 | 152 | -153 | -50% |
| HOSE CUT LENGTH (mm) | 1,550 | 425 | -1125 | -73% |
| HOSE ROUTING WIDTH (mm) | 710 | 399 | -311 | -44% |
| HOSE ROUTING HEIGHT (mm) | 990 | 526 | -436 | -47% |
| HOSE ROUTING AREA (M²) | 0.70 | 0.21 | -0.49 | -70% |
| HOSE ROUTING VOLUME (M³) | 0.026 | 0.007 | -0.019 | -72% |
| HOSE UNIT PRICE ($U.S./mm) | $0.10 | $0.10 | | |
| HOSE PRICE ($U.S.) | $155.00 | $42.46 | -$112.54 | -73% |

**Fig. 6B: Comparison of hose routing area.**



# Hose

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hydraulic hoses can provide many potential design benefits to hydraulic engineers.

## Coupling's importance

While hose selection is important, equally critical is the coupling that allows the hose to attach to other components in the hydraulic system. The hose-coupling interface is one of the most critical but often overlooked design aspects of hydraulic hose assemblies.

A hose rated for 3,000 psi of working pressure and a coupling rated for 3,000 psi does not guarantee that the hose assembly is rated at 3,000 psi. The pressure rating of a hose-coupling interface depends largely on how the coupling is connected to the hose and the study of their interactions. Improper design of the hose-coupling interface can result in a lower pressure rating, reduced life or—even worse—a catastrophic failure.

The engineering science of couplings has advanced along with the hydraulic hose over the years to create a high-performance system. Older coupling designs requiring skiving to remove the outer cover of the hydraulic hose have almost been eliminated. Skipping this step speeds up the process of building assemblies and improves the quality and repeatability of the process, thus reducing the risk of hose failure and injuries.

Modern couplings use "bite-the-wire" technology allowing serrations in the coupling ferrule to pierce through the hose cover and engage with the hose wire reinforcement for maximum coupling retention (**Fig. 11**).

Optimization of the coupling design for stresses and materials using computerized finite element analysis yields further benefits. As **Fig. 12** shows, optimized designs can improve the strength at nut locations to allow mechanics to fully wrench on the coupling during installation, but they can also remove material in less-critical areas to lighten the coupling. The end result is a modern coupling offering simplified assembly with maximum pressure ratings and leak-free performance.

Many factors affect the hose-coupling interface, including stem design, ferrule design, hose reinforcement and hose tube material. Three of the most important factors are hose dimensions, coupling dimensions and crimped dimensions. All these factors are variable, and these variables must be controlled to maximize the useful life of a hose assembly.

Dimensional variance can be reduced, but not eliminated, through high quality manufacturing processes. Crimp dimensions will also deviate from an exact dimension because of the hose and coupling dimensional variance as well as the crimp method, die wear, crimper performance and other external factors. The variations in both the hose and coupling can be adequately managed when both are designed to work together. This approach of "matched systems" is reinforced by industry standard SAE J517, which submits that hoses, couplings and assembly equipment (i.e. crimpers) from different manufacturers are generally not interchangeable.

One measure of the longevity of hydraulic hose assemblies is impulse life, which quantifies how many impulse cycles a hose assembly can withstand before failing to maintain pressure. Hose life in real world applications can be impacted by external factors such as temperature exposure, ozone and abrasion, but the standardized laboratory test measuring impulse life eliminates these external factors to evaluate the hose, coupling and hose-coupling interface specifically. The quality of the components that make up a hose assembly and the resulting hose-coupling interface specifically impact impulse life.

Impulse life can be maximized when hydraulic hose assemblies are designed to account for the following:

- The hose-coupling interface;
- The manufacturing control of all of the components of an assembly; and
- The definition of crimp specifications for specific crimpers and dies, validated with stringent and repeatable test requirements.

Robust hydraulic hose assembly providers do exactly this—design hoses and couplings to work together as a system, and then specify crimp dimensions considering the hose and coupling materials and tolerances to ensure the safety of the hydraulic system and maximize impulse life.

Each factor affecting the hose-coupling interface is taken into account during hose design and manufacture, and continual validation is performed to ensure that the hose and couplings work together to make a high performance, risk-free hydraulic hose assembly. Hose dimensions, coupling dimensions and crimp dimensions are all important factors whose variation can impact impulse life. By controlling the variation in these factors from the nominally ideal values, the hose impulse life is maximized (**Fig. 13**).

If hose and couplings are not designed for each other, or sources of variation in hose-coupling interface are not accounted

**Fig. 7: Computer modeling comparison of fluid pressure flow.**

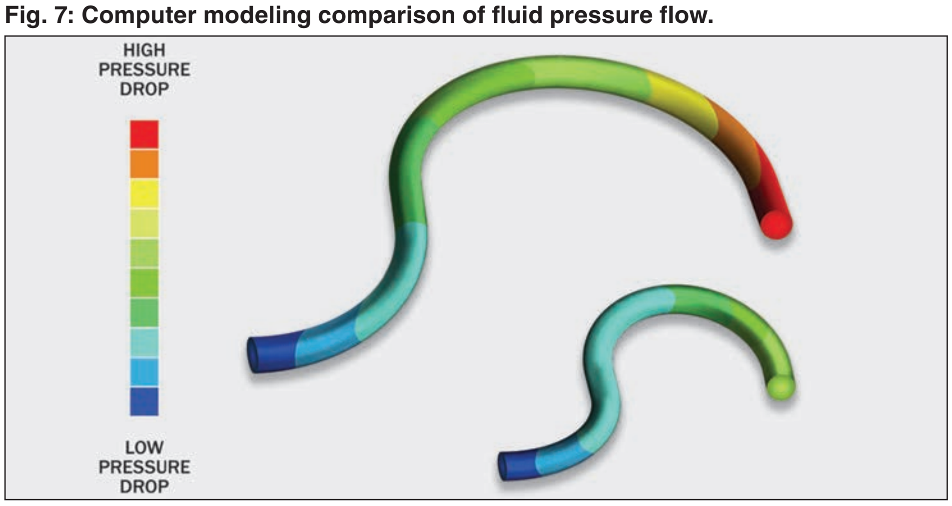



**Fig. 8: Reductions for hose and hydraulic fluid weights.**

| -16 SIZE HOSE | 100R2 | MODERN | DIFFERENCE | REDUCTION |
|---|---|---|---|---|
| WEIGHT PER UNIT LENGTH (kg/100 meter) | 143 | 100 | -43 | -30% |
| CUT LENGTH-HOSE WEIGHT (kg) | 2.22 | 0.42 | -1.8 | -81% |
| HYDRAULIC FLUID WEIGHT (kg) | 15.1 | 3.6 | -11.5 | -76% |
| TOTAL WEIGHT (kg) | 17.3 | 4.0 | -13.3 | -77% |

**Fig. 9: Reduction estimates for improved impulse cycles—duty life.**

| -16 SIZE HOSE | 100R2 | MODERN | DIFFERENCE | REDUCTION |
|---|---|---|---|---|
| IMPULSE TEST (cycles) | 200,000 | 600,000 | 400,000 | -200% |
| NUMBER OF HOSE REPLACEMENTS FOR EACH MODERN HOSE | 3 | 1 | | |
| ASSEMBLY PRICE (Hose $U.S. from Fig6A + $20 for Couplings) | $175.00 (x3) | $62.46 | -$112.54 | -64% |
| INSTALLATION COST ($U.S.) | $2.00 (x3) | $1.00 | -$1.00 | -50% |
| DOWNTIME COST ($U.S.) | $1,000 (x3) | $1,000 | | |
| REPLACEMENT COST ($U.S.) | $3,531 | $1,063 | -$2,468 | -70% |

**Fig. 10: Reduction estimates for multiple hose assemblies on a single machine.**

| -16 SIZE HOSE | 100R2 | MODERN | DIFFERENCE | REDUCTION |
|---|---|---|---|---|
| NUMBER OF HOSE ASSEMBLIES PER MACHINE | 15 | 15 | | |
| TOTAL HOSE CROSS SECTIONAL AREA ($mm^2$) | 16,655 | 14,514 | -2,141 | -13% |
| TOTAL ROUTING AREA ($M^2$) | 10.5 | 3.2 | -7 | -70% |
| TOTAL ROUTING VOLUME ($M^3$) | 0.4 | 0.1 | -0.3 | -72% |
| TOTAL WEIGHT OF HOSE/FLUID (kg) | 259.3 | 60.3 | -199.0 | -77% |
| TOTAL HOSE LENGTH (mm) | 23,250 | 6,368 | -16,882 | -73% |
| TOTAL REPLACEMENT COST ($U.S.) | $52,965 | $15,952 | -$37,013 | -70% |

**Fig. 11: "Bite-the-wire" coupling eliminates need for hose skiving.**

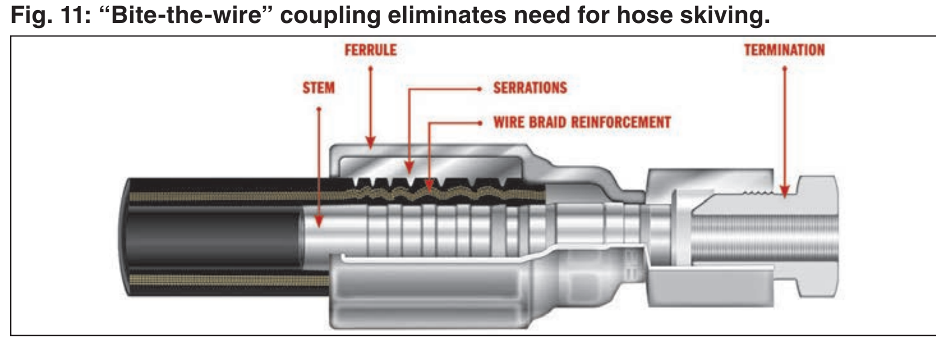



**Fig. 12: Computer finite element analysis optimizes coupling design.**

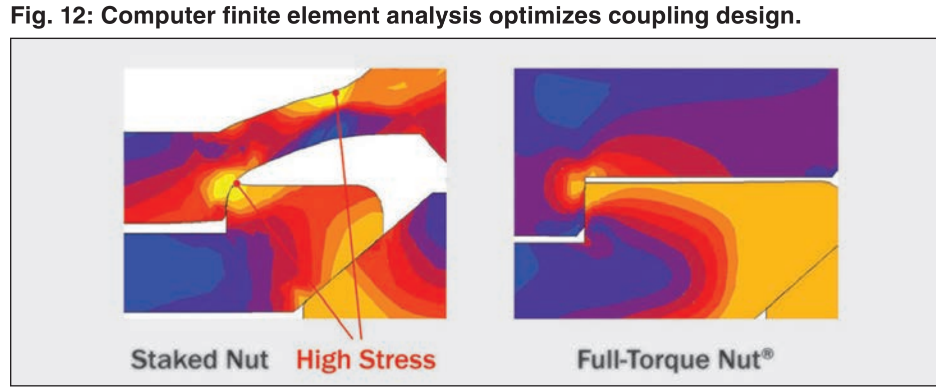



**Fig. 13: Maximum performance achieved by minimizing hose-coupling variation.**

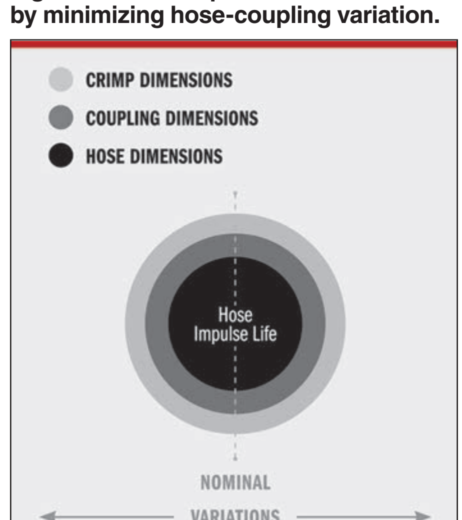
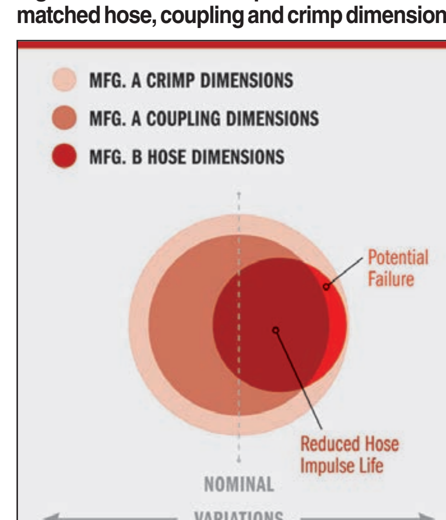



**Fig. 14: Reduction in impulse life due to mismatched hose, coupling and crimp dimensions.**



for in design and testing, hose performance can be drastically reduced to the point of catastrophic failure when hoses and couplings are not specified to work together as a system.

**Fig. 14** shows what might happen if components from multiple manufacturers are not designed to work together. A coupling from Manufacturer A and a hose from Manufacturer B are being assembled. The crimp specifications from Manufacturer A don't account for the hose variation from Manufacturer B. These crimp specifications may not adequately interface the hose and coupling, risking a failure of the hose in operation. In the best case scenario, the hose assembly will see significantly reduced impulse performance as compared to a hose assembly that is designed as a system and validated through a rigorous test regiment.

The stacking of tolerances between the hose, coupling and crimp dimensions can also result in reduced impulse life. **Fig. 15** shows a hose that is smaller than expected being assembled with a coupling that is larger than expected. The same crimp dimensions may not yield a proper hose-coupling interface, risking a coupling blow-off or reduced impulse life. Clearly, the risk of failure increases when combining variation from the hose, coupling and crimp dimensions.

As variation increases even slightly for each component, a significant reduction in hose assembly life can be expected, and the risk for catastrophic failure increases. If the hose, couplings and crimp tolerances have been designed for each other and have passed the exacting standards of a system manufacturer, assembly performance and reliability should be maximized.

## Crimper technology innovation

Advancements in crimping machines are helping to ensure the proper hose-coupling interface is achieved for optimal performance of the hydraulic hose assembly. Traditional hose crimpers have relied on many manual processes that could lead to errors at many steps. Operators would have to consult multiple paper manuals to determine the proper crimp values for a given set of hose and coupling along with the settings required on the crimper machine itself. After manually crimping the hose-coupling, the operator would need to use a caliper to measure the crimp and determine if it falls within acceptable tolerances.

Crimper technology has modernized to incorporate information technology to automate the crimping process. This minimizes the potential for errors, simplifies operator training and improves productivity.

Modern crimpers have built-in digital interfaces with informational databases on all the hose and couplings parts to eliminate the need for paper catalogs that are out-of-date as soon as they are printed and are easily misplaced in a busy hose assembly shop. Crimp data is automatically and routinely updated via wireless internet connection so the most recent information is always available.

Barcoding of hoses and couplings can enable instant reference of component information to verify compatibility and correct component selection. Guided on-screen instructions guarantee proper selection of crimping dies, and crimp machine settings are automatically updated. After digitally providing the necessary crimping force, modern crimpers can then measure the crimp outside diameter dimension automatically to verify a proper crimp has been achieved.

Furthermore, modern crimper systems can even record and print a report of individual crimp values to provide customers. The latest crimper systems make high-quality hydraulic assemblies the first time, every time, taking the guesswork out of the production of hydraulic assemblies (**Fig. 16**).

**Fig. 15: Stacking of tolerances increases risk for failure and reduced impulse life.**

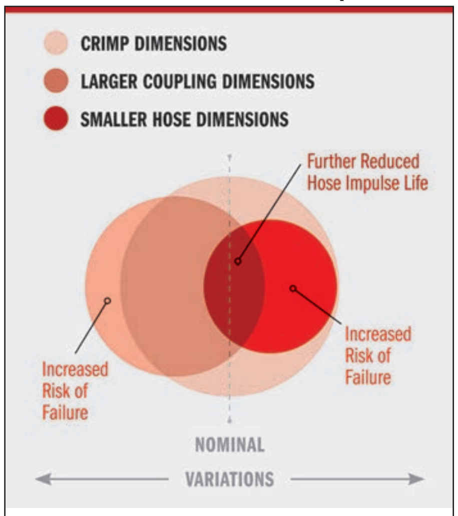



**Fig. 16: Hydraulic crimper with integrated information technology.**