DEVELOPMENT OF HYDRAULICS
IN THE
TRANSPORT INDUSTRY

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When I started my apprenticeship as a Fitter and Turner 27 years ago and was presented with my first telescopic cylinder to repair, I thought to myself there has to be a better way of building these things.

It took 15 years of hoist repair headaches plus much saving and expansion for the last 5 years of that 15 years to achieve a position where I could do something about hoist design.

That point was reached 12 years ago, but before we look at recent history we would do well to look at the standard product that was common usage prior to 12 years ago.

All of the product that was in the market place at that time was based on 20 to 30 year old technology or older.

Because of the principles involved with the function of telescopic hydraulics which require a sealing device between each tube it is possible to use bore (bottom sealing) or outside diameter (top sealing) to achieve this end.

The advantage of bottom sealing is the greater effective area available with a given tube size resulting in a lower working pressure and hence less seal lip loading on semi finished surfaces.

It is also possible to reduce the number of dynamic sealing lips by 50%. Cylinders of this design were mostly of U.K. origin.

Top sealing cylinders of this era all used Vee rings or "Chevron" style packings which required an open top adjustable gland for effective OD sealing. The advantage of top sealing cylinders is that they are true displacement cylinders, require OD finishing only and could be resealed with only partial dismantling. Cylinders of this style were of Australian and American origin.

In the evaluation process of selecting bottom sealing or top sealing principles it was necessary to look at the disadvantages of both.

The major problem with bottom sealing cylinders is that the annular area must breath to atmosphere. This allows contamination of the annular area causing accelerated wear to the tubes, bearings and seals.

When considering design improvements to increase the leak free working life of telescopic cylinders, bottom sealing cylinders were the first I investigated because of the "agricultural" designs that were being used.

The inability to prevent ingestion of contamination into the annular area caused this project to the scrapped and bottom sealing cylinders to be placed in the same category as the dinosaurs.

This doesn't mean that the top sealing designs being used at that time were much better. Because all manufacturers were using Vee ring packing requiring top and bottom adaptors and an open gland the resultant nut stack greatly reduced the effective stroke of the larger stages therefore increasing the closed height.

Manufacturing methods were also "agricultural" in that the bottom bearing ran in as drawn tube with large clearances or as machined tube resulting in

accelerated wear. These "loose" piston designs resulted in the need for large gland bearing areas which tended to complicate the internal design of the gland. The most popular method of gland bush retention was by threading. These threads could become distorted or silted which could cause difficulty in replacing or servicing.

Another method popular with American designs was the use of spiral circlips. These circlips had to act as end of stroke stops as well as gland bush retention devices. The edge of the circlip groove would distort causing the removal of the spiral circlip to be nearly impossible. In most cases the only way to completely strip this type of cylinder was to machine the base of the outer and machine the pistons of each stage.

The other major drawback with the top sealing cylinders produced at that time was the method of outside diameter tube finishing that was used. Some manufacturers used as drawn tube either untouched, linished or roller burnished and had various ID gland bushes to suit. This practise allows poor tolerance control and a soft sliding surface for the seals which results in accelerated wear and leakage.

The major concerns that end users had in regard to hoist performance were:-

1.   Leakage;
2.   Seal life;
3.   Safety of mechanical design;
4.   Ease of maintenance;
5.   Weight to performance ratio.

In addressing these concerns we had two things in our favour:-

1.   The evolution of higher pressure rated PTO Pumps;
2.   The increased affordability of flexible machining
      technology.

The problems created by leaking hoists have increased significantly over the past 12 years to the point that in some areas a vehicle creating a road safety and environmental hazard by dropping oil on the road is considered unroadworthy.

These efforts are to be applauded in high usage metropolitan areas where light rain mixed with dropped oil can cause extremely hazardous road conditions.

When addressing the design problems associated with seal leakage and seal life the solving of mechanical strength came as a natural extension. These three criteria could be satisfied by using a precision version of the existing top sealing designs but with one major drawback. All those blasted threads.

If we wanted a simple, easy to maintain, precision manufacture at an affordable price, high performance to weight ratio leakfree hoist we need to perfect unitary construction.

Once the decision was made to develop unitary construction the next major problem was the selection of the metal finishing process for the tube sealing surface.

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SURFACE TREATMENT FOR TELESCOPIC HYDRAULIC CYLINDERS

The industry standard for Telescopic cylinders has in the past been a tolerance of sub-standard surface treatments such as roller burnishing, as drawn or ground and linished surface finishes. All of these treatments did little for the wearability and corrosion resistance of the material.

The selection of a more suitable base material than 1026 CDS or DOM tubing is defeated on economic or process grounds. Hence we have no viable alternative other than to provide a surface treatment for the commercially available tube material.

The search for a suitable surface treatment for telescopic cylinders has been regulated by two major considerations:-

1. Technology available;
2. Chemical composition of available base materials.

Because of the low carbon content of the base material standard heat treatment processes were ruled out. The only alternative was for the surface to be coated or modified to achieve corrosion and wear resistance. The commercially available processes are listed below:-

1. Hard Chrome Plating;
2. Salt Bath Nitriding;
3. Electroless Nickel;
4. Gaseous Nitro Carburising;
5. Ceramic Coating;
6. Ion Implantation.

All of the above processes have a varied result to improving the surface of the base material. Items three and four are widely used in industry for smaller items but require an extensive plant infrastructure coupled to large volume production to be a viable alternative to Items one and two, so were ruled out. Items five and six are new technologies that have yet to be developed to the extent Items one to four have been and are not economically viable at this time. This leaves the two alternatives as Items one and two which are approximately equal in cost application so we should look at the quality of results.

Chrome plating of piston rods for hydraulic cylinders has been standard practice for years, but it is only recently that the process has been developed to enhance its corrosion inhibiting characteristics.

Late in the first quarter of the twentieth century, a practical process for hard chromium plating was commercialized by United Chromium, a predecessor company of M & T Harshaw. Many evolutionary and two major inventive advances led, in the past decade, to HEEF 25 chemicals for hard chromium plating; these have achieved much success and wide acceptance.

Capable of operating at higher current densities and with greater efficiency than the conventional chromic acid - sulfate bath, HEEF 25 chemicals reduce both the time required for plating and the electrical power required for a given chromium deposit. Etching and iron contamination problems characteristic of the mixed catalyst fluoride containing baths are eliminated with the HEEF 25 method.

In addition, chromium deposits from the HEEF 25 process have proven to be harder, smoother, brighter and more durable. Consequently, the process has enjoyed wide industry acceptance and is currently being used successfully by many major companies around the world, including Toyota Motor Corporation and Kayaba Industry Company Ltd.

The superior performance of chromium deposits from the HEEF 25 process has been quantified by an exhaustive testing procedure designed to establish the wearability, corrosion resistance and effects of variations in the plating conditions.

Tests have demonstrated that the HEEF 25 process results in chromium plating exhibiting superior performance characteristics and greater consistency of results than are obtained by alternative methods.

The testing procedures and subsequent data are presented in this report, which we are pleased to submit for your review.

WEAR PROPERTIES
Which method provides chromium plating that stands up best?

1. TESTING FOR: Resistance to dry abrasion.

METHOD: The Taber Abraser, an industry standard, was used to measure dry abrasive wear on samples, chrome-plated by each of the three plating processes: the conventional, mixed catalyst and HEEF 25 chromium plating methods. The sample was placed on the instrument's revolving sample holder and a load was applied, rubbing against the sample's surface. A vacuum picked up residual particles to prevent their affecting the abrasiveness. The weight loss of the sample after a given number of·revolutions provides an indication of its relevant resistance to abrasive wear.

RESULTS: Figure 1

Taber Abraser Wear Test

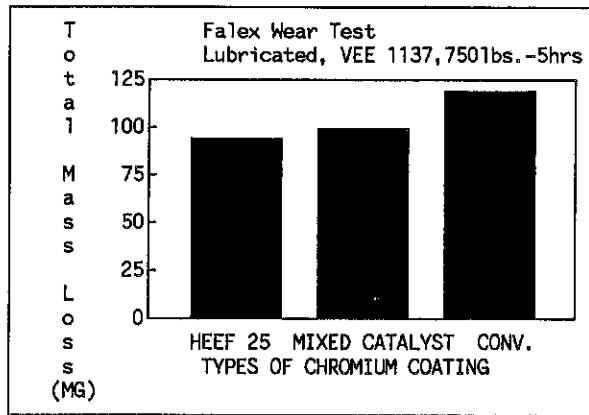Mass Loss (mg) vs TYPES OF CHROMIUM COATING: HEEF 25, MIXED CATALYST, CONV.
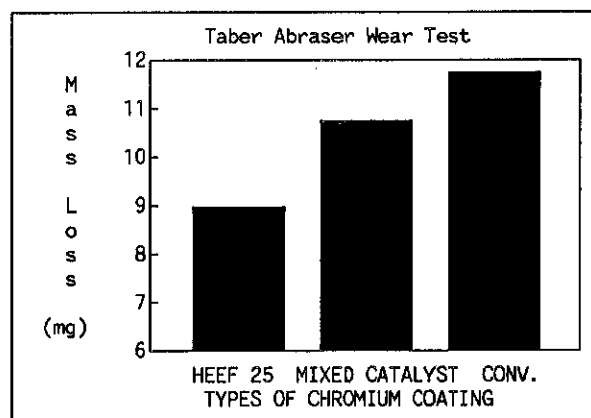
CONCLUSION: Hard chrome deposits obtained from the HEEF 25 process exhibited significantly less wear than mixed catalyst deposits and nearly 25% less than conventional deposits.

2. TESTING FOR: Resistance to lubricated sliding wear.

METHOD: The Falex Lubricated Wear Tester used conventional mixed catalyst and HEEF 25 hard chrome plated pins, revolving at 270 revolutions per minute between two unplated steel blocks while immersed in a temperature controlled oil bath. With a measured force, the blocks are pressed against the pin,

creating wear which is calibrated by measuring the weight loss of both the pin and the blocks.

RESULTS: Figure 2

Figure 2: Falex Wear Test
Lubricated, VEE 1137, 750lbs.-5hrs
Total Mass Loss (MG) vs TYPES OF CHROMIUM COATING (HEEF 25, MIXED CATALYST, CONV.)
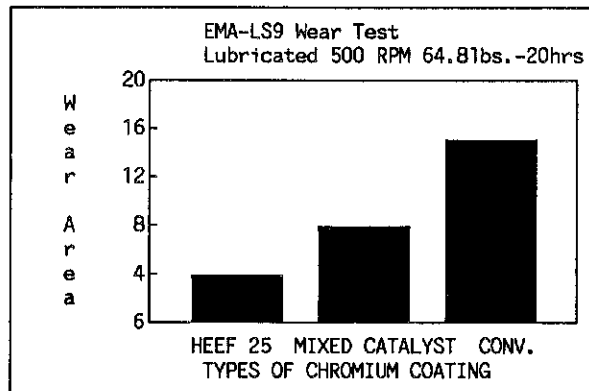Y-axis: 0, 25, 50, 75, 100, 125

CONCLUSION: Hard chrome deposits obtained from the HEEF 25 process consistently exhibited significantly more resistance to sliding wear than samples plated from mixed catalyst and conventional chemistries.

3. TESTING FOR: Lubricated cylinder wear (simulated).

METHOD: A new testing apparatus providing for laboratory simulation of cylinder wear was developed at the University of Michigan. This simulator, designated EMA-LS9, recreates the relative part geometries of an engine and duplicates the engine's operating conditions utilizing three variables: lubrication, pressure and temperature. For the tests, piston rings were plated using all three chemistries; the HEEF 25 system, mixed catalyst and conventional chromium plating processes. Each type of plated ring was tested in the engine simulator and wear was measured by the size of the worn area.

RESULTS: Figure 3

Figure 3: EMA-LS9 Wear Test
Lubricated 500 RPM 64.8lbs.-20hrs
Wear Area vs TYPES OF CHROMIUM COATING (HEEF 25, MIXED CATALYST, CONV.)
Y-axis: 6, 4, 8, 12, 16, 20

CONCLUSION: Piston rings plated with the HEEF 25 process demonstrated up to four times conventional chrome resistance to wear under the simulated cylinder conditions - i.e. linear motion.

CORROSION RESISTANCE
Which chromium plating method provides the best protection for the plated substrate?

TESTING FOR: Chromium plating protection of substrate.

METHOD: Corrosion resistance is the summation of pre-plating, plating and post-plating processing, and of the plating bath chemistry. In order to examine only the effect of the bath chemistry, tests were performed with as much control of pre-plating and post-plating variables as was possible. To minimize the pretreatment effects, standardized steel rods from only one lot of steel were prepared by the same methods with final polishing using 600 grit silicon carbide paper. The samples were then plated in each of the three basic bath chemistries under conditions that were optimum for each process. No post-plating processing, such as grinding, buffing or super finished, was done in order to eliminate this as a variable. The samples were then subjected to Neutral Salt Spray Testing to acquire comparable corrosion data.

In determining the effectiveness of a plating process to protect the substrate, an analysis of the chromium microcrack density was made. Deposits with low microcrack densities have microcracks that are longer and tend to extend to the substrate. In chromium deposits with a higher microcrack count, the microcracks are shorter and shallower, providing superior protection to the substrates under corrosive conditions.

Corrosion follows the pathway of microcracks since these represent a more easily corrodible environment. The fewer microcracks, the deeper and longer they are. The HEEF 25 hard chrome plating process produces many shallow microcracks, so less corrosion.

CONCLUSION: In all cases, the HEEF 25 process resulted in less corrosion failures than the other two methods of plating. This is further substantiated in the SAE Paper 890146 by Kent Stout, Eaton Hydraulics Division, Hutchison, Kansas: "Historically, achieving corrosion resistance was pursued as an attempt to correct some defect in the plate. Various plating baths operating under divergent conditions were used for production rods. Alternatives to industrial hard chromium plate were investigated, including crack-free chromium plate, duplex nickel chromium plate, nitro carburizing and stainless steel. All were unsatisfactory due to their wearability and/or corrosion resistance. A series of laboratory plating runs demonstrated that a decrease in the area rusted of approximately 35% could be achieved by converting the bath to HEEF 25 (hard chrome plating method)."

VARIABILITY
How are deposit characteristics affected by variations in bath chemistry and operating conditions?

TESTING FOR: Variations in deposit properties such as hardness and wear as a result of fluctuations in temperature, current density and/or bath chemistry of a plating bath using HEEF 25 chemicals.

METHOD: Since small changes in conventional bath parameters are known to cause measurable variations in the chromium deposit's hardness and wear resistance, this study was undertaken to determine the effect of such changes on the deposits obtained with the HEEF 25 process.

Variations, within acceptable parameters, from the "Lab Standard" bath which are normal and expected in real world operation were tested. Also bath samples taken from operating commercial plants were tested in an identical manner.

The Lab Test: Several samples were chromium plated in baths using HEEF 25 chemicals with a wide range of operating conditions. In each test series, the

baths were prepared with newly mixed components under laboratory conditions, with all parameters but one being kept constant. the lone variables included chromic acid concentration, temperature and current density. Each variable underwent a range of alterations, with samples taken in each case. After plating, the deposits were subjected to Knoop microhardness measurements and Falex wear tests to ascertain what effect varying the HEEF 25 bath conditions had on the chromium deposit.

Relative constancy, even in the face of controlled variables was achievable under laboratory conditions.

The Field Test: In the field, however, the baths are at the mercy of operational vagaries. They are subjected to constant use, chemical contamination, and imprecise adjustments. To determine how great the difference was between the laboratory mix and the actual field bath (a ± 20%) variance was anticipated), the following test was performed.

Plating bath samples were collected arbitrarily, unannounced and at random from nineteen plating facilities using the HEEF 25 process, with customer approval and understanding of the testing. The solutions were analyzed, revealing a wider chemistry range than was used in the laboratory studies.

The baths taken from the field were then used for plating test samples, duplicating the specific customer's temperature and plating current density. The deposits were subjected to Knoop microhardness and Falex wear tests, as in the lab test.

RESULTS: Figure 4
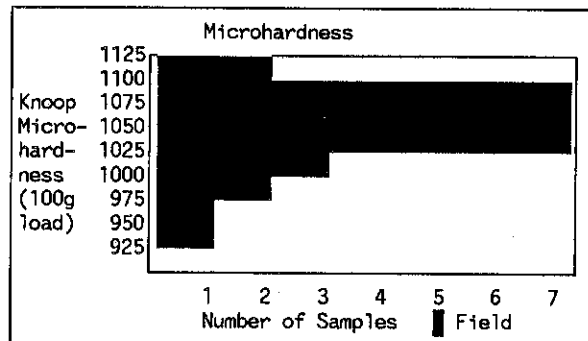
RESULTS: Figure 5
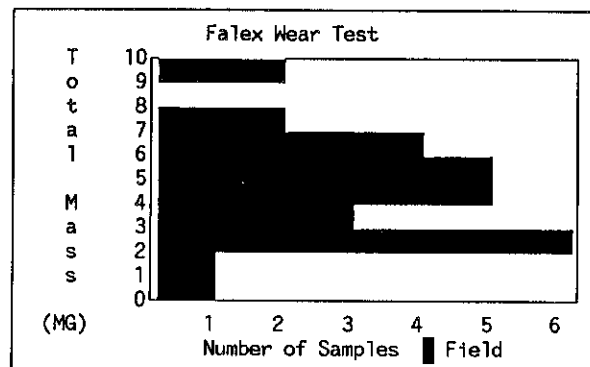
CONCLUSION: Under controlled laboratory conditions and in actual field environment, chromium deposits from the HEEF 25 process yield surprisingly

consistent physical properties over a wide range of bath operating conditions. Knoop microhardness and Falex wear tests show that deposits from the HEEF 25 process exhibit less variation than deposits from conventional plating chemistries.

SUMMARY
In all three categories of tests and in each individual test, chromium deposited using the HEEF 25 hard chrome plating method proved superior to both the conventional and the mixed catalyst procedures. These studies, as well as real world experience, confirm that deposits from the HEEF 25 process significantly outperform other hard chromium coatings. When a design calls for hard functional chromium plating, the superior wear properties and corrosion protection provided by the HEEF 25 process assure brighter, harder and more durable deposits, with less part to part variability. The HEEF 25 process has proved to be a superior chromium plating method in every way.

NITRIDING

Nitriding is a process of case hardening in which an iron-base alloy of special composition is heated in an atmosphere of ammonia or in contact with a nitrogenous material. Surface hardening is produced without quenching.

Nitriding of low carbon steels such as 1026 gives little benefit because of the very thin layer of ferro nitrogenous material that is developed (10-15 microns) over an unimproved substrate.

·It is therefore unwise to use nitriding on unalloyed low carbon steels as they form an extremely brittle case that spalls readily and the hardness increase in the diffusion zone is small.

Therefore to achieve a suitable surface treatment on SAE 1026 tube it is necessary to use a nitro-carburising process.

Nitro-Carburising Treatments/Ferritic Nitrocarburising

Ferritic nitrocarburising processes are thermochemical treatments which involve diffusion additions of both nitrogen and carbon to the surface of ferrous materials at temperatures within the ferritic phase field.

The primary object of such treatments is usually to improve anti-scuffing characteristics of ferrous engineering components by providing the surface with a 'compound layer' which has good tribological properties. In addition, the material's fatigue characteristics can be considerably improved, particularly when nitrogen is retained in solid solution in the 'diffusion zone' beneath the compound layer. This effect is normally achieved by quenching into oil or water from the treatment temperature.

Salt Bath Nitrocarburising Treatment

Although a number of cyanide nitrocarburising treatments are in use, it is often difficult to differentiate between many of them because of a distinct lack of detailed scientific data about each process. The literature, however, reveals that there are two main treatments of which all other processes appear to be minor variants. These patented processes have the trade names 'Tufftride' (called Tenifer in Europe) and 'Sulfinuz'.

The names of processes which have been used as alternative treatments to the Tufftride process include Mild Nitriding, Activated Nitriding and Aerated Bath Nitriding. Names which have been used for minor variants of the Sulfinuz treatment include Sulphidizing, Sulfurizing, and Sulfocyaniding.

In the Tufftride and Sulfinuz type processes, components are preheated to about 350 to 400°C, and then transferred to the nitrocarburising salt bath at 570°C. The essential ingredients of the baths for both processes are normally alkali metal cyanide and cyanate. At the treatment temperature, 570°C, the Tufftride process is controlled largely by two reactions - an oxidation reaction and a catalytic reaction.

The oxidation reaction involves transformation of sodium cyanide to sodium cyanate:

$$4NaCN + 2O_2 \rightleftharpoons 4NaCNO$$
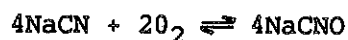
Though this reaction can proceed by natural oxidation of the cyanide bath, eventually leading to the desired cyanate content, the mechanism is largely uncontrollable. To provide agitation and stimulate chemical activity, therefore, dry air is introduced into the bath.

The catalytic reaction involves breaking down of sodium cyanate in the presence of the steel components being treated, thus supplying carbon and nitrogen to the surface:

$$8NaCNO \rightleftharpoons 2NaP_2CO3 + 4NaCN + CO_2 \; (C)F_e + (4) \; N \; F_e$$

As a result of this treatment, a wear-resistant compound layer, rich in nitrogen and carbon, is formed on component surfaces. Thickness of the layer, typically in the 8 to 20µ range, depends on the material being treated and the process time, which is usually less than 3 hours.

With the Sulfinuz treatment the same basic oxidation and catalytic reactions also occur. In addition, further reactions take place because of sulfites in the melt. These sulfites are reduced to sulfides, in conjunction with the oxidation of the cyanide to cyanate, as follows:

$$Na_2SO_3 + 3NaCN \rightleftharpoons Na_2S + 3NaCNO$$

Thus the sulphur present in the bath effectively acts as an accelerator, with the result that the cyanate is produced more readily than if the sulphur compound were absent.

The composition of a salt bath layer is given in Figure 1 below:
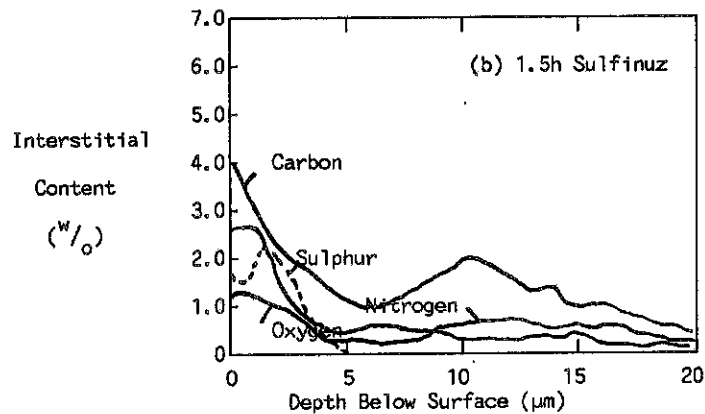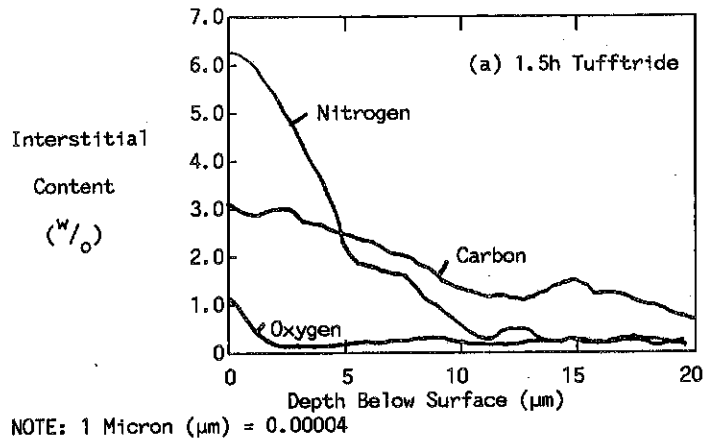
NOTE: 1 Micron (μm) = 0.00004

Figure 1   Electron microprobe traces, (a) nitrogen, carbon and oxygen in the compound layer formed by a 90 min. Tufftride treatment; (b) nitrogen, carbon, oxygen and sulphur in the compound layer formed by a 90 min. Sulfinuz treatment.

The types of liquid nitriding processes are given in Table 1:

TABLE 1

Process Identification	Operating Range Composition	Chemical Nature	Suggested Pool Treatment	Operating Temp. °C	°F	U.S. Patent Number
Aerated cyanide cyanate	Sodium cyanide (NaCN$_2$) potassium cyanide (KCN) and potassium cyanate (KCNO), sodium cyanate (NaCNO)	Strongly reducing	Water or oil quench: nitrogen cool	570	1060	3 208 685
Casing salt	Potassium cyanide (KCN) or sodium cyanide (NaCN) sodium cyanate (NaCNO) or potassium cyanate (KCNO) or mixture	Strongly reducing	Water or oil quench	510-650	950-1200	...
Pressure Sodium nitriding	Sodium cyanide (NaCN) sodium cyanate (NaCNO)	Strongly reducing	Air cool	525-565	975-1050	...
Regenerated cyanate-carbonate	Type A - Potassium cyanate (KCNO), potassium carbonate (K$_2$CO$_2$)	Mildly oxidising	Water, oil, or sale quench	580	1075	4 019 925
	Type B - Potassium cyanate (KCNO), potassium carbonate (K$_2$CO$_2$), 1-10ppm, sulphur (S)	Mildly oxidising	Water or oil quench, or salt quench	540-575	1000-1070	4 006 043

Hardness of Compound Layer

Shall be determined by microhardness measurements in accordance with ASTM E384 on the nitriding surface or on metallographically prepared cross-sections of the nitrided case using Knoop or other appropriate hardness tester, as agreed upon by purchaser and vendor as follows:

MATERIAL	HARDNESS, MIN (HK/200)
Carbon steels	300
Low-alloy steels	450
Tool and die steels	700
Corrosion and heat resistant steels	900
Ductile, Malleable, and gray cast iron	600
Powder metal products (ferrous)	600

TABLE 2
RECOMMENDED NITRIDING PROCEDURES

MATERIAL	RECOMMENDED TIME		TEMPERATURE	
	min	max	°C	°F
Carbon and low-alloy steels.........1 h		2 h	580 = 5	1075 = 10
Tool and die steels (structural)....30 min		3 h	540-580	1000-1075
Tool steels (cutting)...............5 min		1 h	540-580	1000-1075
Corrosion and heat resistant steels.1 h		2 h	580 = 5	1075 = 10
Ductile, malleable, and gray cast iron.................1 h		4 h	580 = 5	1075 =10
Powder metal products (ferrous).....30 min		2 h	580 = 5	1075 = 10

TABLE 3
DEPTH OF COMPOUND LAYER

MATERIAL	CASE DEPTH			
	mm		in.	
	min	max	min	max
Carbon and low-alloy steels.........0.0038-0.03			0.00015-0.001	
Tool and die steels (structural)....0.003 -0.013			0.0001 -0.0005	
Tool steels (cutting)...............0.003			0.0001	
Corrosion and heat resistant steels.0.0038-0.03			0.00015-0.001	
Ductile, malleable, and gray cast iron.................0.0038-0.03			0.00015-0.001	
Powder metal products (ferrous).....0.0038-0.03			0.00015-0.001	

The maximum hardness that has been achieved on low carbon non alloy steel such as SAE 1026 is 650-700 Knoop. This figure was achieved after four hours of immersion and without stress relieving or ageing.

The 'white' or compound layer was 8-12 micron with a hardened depth of .001".

The 'white' layer provides the corrosion protection.

CONCLUSION:
There is a dramatic difference between the hardness figures achievable with HEEF 25 (1050-1100 Knoop) and Nitriding 650-700 Knoop which would result in a far longer life per .001" of thickness for HEEF 25 hard chrome.

Choosing hard chrome plating also has the advantage of being able to select a thicker coating (usual minimum thickness 0.0015"-0.002) if desired. Hard chrome is also an added coating which can be stripped and replaced if necessary, hence preventing scrapping of the worn components.

It is therefore plain to see why every major equipment manufacturer in the world uses hard chrome plating on their hydraulic cylinder rods (see SAE paper 890146 by Kent Stout, Eaton Hydraulics Division, Hutchison, Kansas).

* * *

Having established the superior performance associated with hard chrome plating the selection of the correct metal finishing process was easy. By combining the latest in metal finishing technology with unitary construction it was now possible to produce a leakfree cylinder.

Unitary construction of hoist stages, first developed in Australia 16 years ago, has spread to America and Europe to become the standard by which other hoist designs are compared.

There are many advantages in using unitary construction as it solves all of the end user concerns related to earlier.

Leakage and seal life are continually being improved by the ability to utilize the latest developments in mono seals and bearing materials.

The mechanical design problems are solved in the integral tube gland and piston design resulting in greater wall thickness in the critical areas.

The complete removal of all those threads at the top of the cylinder has solved all of those maintenance and manufacturing problems.

The weight to performance ratio has been improved with the ability to operate at higher pressure plus achieving maximum strokes in a shorter closed length.

These are a few of the benefits that have resulted from the evolution of telescopic cylinders.

We now have the ability to match larger pump and valve combinations to provide faster cycle times and increased productivity.

The future will be smaller hoists working at higher pressures as new tube materials and manufacturing techniques come on stream.

The hydraulic industry is responding to industry needs and stands ready to meet the challenge of the future.

JOHN F. WHITE

<u>INVENTOR</u>

MANAGING DIRECTOR - DELTA HYDRAULICS PTY. LTD.