Del Stanton's CV

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Retired Mechanical Design Engineer. My professional engineering career included the following experiences:

>> Design of the analog electrical controls for film movement or focus and relay control circuits for rear projection screen film film readers. I discovered the best way to design these control systems involved three steps:

A: Write the operator's manual first. Not a final version, but an initial working draft. <u>This forces you to think about the finished control system from the operator's viewpoint</u>. As the design of the control system progresses this document should be updated.

B. Then sketch out the control panel. Decide upon the labels for the switches, push buttons, knobs, and displays. Again this means you are taking the viewpoint of the operator.

C. Then you are properly prepared to design the control circuitry to operate from the control panel you have designed

Note carefully, this is exactly the reverse of the way most control system designers work. First they design the circuit and its controls, then the control panel as a place to hold the switches, buttons dials and displays and finally the operating manual is written at the end of the project. If the operating manual is conscientiously written by someone who really understands the operation the the device (a unlikely occurence in most organizations) it may reveal major errors in the control system design at a time when correcting these errors will be very expensive.

>> I know how to use small AC and DC motors in a controlled manner to perform a multitude of tasks: maintaining proper tension on film supply and take up reels, provide remote switch controlled (bang-bang) lens focusing, developed a better dial controlled focussing system using stepping motor driven by a digital pot with A and B outputs with a 90 degree phase difference, designed a system to change lenses with precision positioning to provide different magnifications with a DC motor .

>> Designed and prototyped a 7400 TTL logic (NOT gated TTL logic which is beyond my ken) control system for a pneumatically operated surgical tool used for cataract eye surgery. This included using binary coded up/down counters with up/down pushbuttons to drive two seven segment LED displays. The same BCD output, through eight BCD scaled resistors and a 741 op-amp wired as a eight input adder, provided the analog control voltage for bang-bang control of a DC motor to used adjust air pressure regulators. A pressure transducer provided the feedback voltage. The two voltages drove a comparator that then drove a H bridge to drive the DC motor coupled to the shaft of the air pressure regulator.

I built the prototype was using a Vector hand-held wire wrap tool and Vector prototyping PC boards. The system had four control channels:

1) Regulating the air pressure to the operating hand piece by a mechanical air pressure regulator driven by a small dc motor and feedback from a pressure transducer at the regulator's output side.
2) Create pulsed bursts of air pressure , a variable pulse rate with a 50% duty cycle. The pulse rate was controlled by a similar set of push buttons, seven segment digital display, BCD to analog conversion with 741 opamp drove a 555 timer and power transistor (before MOSFETs) drove a solenoid valve providing pulsed bursts of pressurizef air that moved the spring loaded piston within the hand piece.
3) The vacuum control channel had the same system as the pressure channel to control a mechanical pressure regulator controlling the air flow to a venturi type vacuum generator, but in this case the feedback supplied by a pressure transducer measuring the vacuum.
4) Finally the intensity of a halogen work light was controlled by a pulse width modulator with up/down push buttons, up/down BCD counter and so forth.
It is a tough job to hand wirewrap fifty or sixty 8, 14 and 16 pin DIP packages following a hand drawn schematic. Now I marvel that by and large everyting worked as I proceeded to wire and test each channel.
>> I understand that knob controls should be optimised so the the smallest movement of the knob provides just discernable change in the function being controlled. For example if a knob controlled focusing control is too sensitive the operator will not be able to acheive sharp focus quickly. If system the errors the other way, with lots of dial motion for any visible effect, the operator often will experience difficulty determing in what direction to turn to acheive focus. Once reasonable focus is attained he is on an apparent plateau. At this point he has to move + or - enough to see a degredation of focus on each side and then turn back to the center to be assured of having achieved the best focus.
>> I designed all the mechanical components and the electrical control circuit for a follow-focus system for an animation stand. As the camera (with a non-zooming lens) was trucked up and down the lens mounts focus control was driven by a small Superior Electric Slo-Syn 72 RPM 120 VAC motor. This a 200 steps/revolution stepping motor with 120 volt coils and a capacitor to change the phase on one winding. Reversing this motor is done exactly the same way as any capacitor start or run AC induction motor is reversed. This motor had two great advantages for this application: instant stop-start capabily within 1/60 of a second (1.8 of a degree of rotation) and the its slow speed that eliminated any need for gearing down from the higher RPM of a conventional motor. I did the calculations and designed the special cam that rotated with the lens's focusing rotation and a spring loaded cam follower driving a single turn potentiometer that provided feedback. The command signal came fron a ten turm potentiometer mounted on the camera carriage that was driven by a 1/32" diameter stranded stainless stell wire making two turns about a pulley mounted on the potentiometer shaft. This wire was tensioned by a coiled extension spring at one end. Thus this ten turn potentiometer measured the distance between the animation stand platen and the camera and supplied the control signal to the bang-bang servo.

The control "electronics" for this system was a simple Allen Bradly differential polarized relay. This relay had two coils and SPDT open center contacts. The closure of either pole contact would run the motor in the correct direction to reduce the focus error was determined by the difference between the currents in these coils. The relay included two internal bipolar transistors to amplify the current from the control and feedback potentiometers without any additional amplification. This relay's deadband could be adjusted by changing the tension on the spring that kept its armature centered. Thus I could easily optimise the performance of this simple bang-bang servo system.

>> I recognized the need for a small light transducer while working as the Sales Manager for the Systems Division of United Detector Technology. (I define a "light transducer" as a product that linearly converts the intensity of the light striking a photodector into a DC output voltage.) This was the company that pioneered the use of silicon solar cell technology to produce silicon PIV photodetectors. Such a silicon cell photodetector detector can be reverse biased to reduce its capacity and thus speed its response or it can be optinumally loaded to set its operation point along the current vs. voltage curve to the maximim power point, again sacrificing any linearity. (Solar cell open circuit voltage maximum voltage but no current but no power since P = I * V. Solar cell shorted, high current but no voltage so zero power again. Optinum power point is somewhere between these extremes.) To achieve linear output a silicon detector must deliver its generated current at zero volts. This is accomplished by connecting an operational amplifier as a current to voltage converter , also called a transimpedance amplifier. The input of the transimpedance amplifier provides a zero voltage current sink to adsorb the output of the silicon photodetector.

United Detector was thus presented with a problem when introducing the concept of a silicon PIV photodiode as a photodetector. Their salesman would show an enginner their product and the enginneer would say, "Great let's go back to the lab and try it out". But his lab didn't have the transimpedance amplifier required. So United Dector put a 741 op-amp in a box with a couple of 12 volt mercury batteries, two BNC conmnetectors and an On/Off switch. This was intended simply as a demonstration device for their salesmen. But when an engineer bought a silicon photodiode he often wanted to buy one of these demo boxes as well. So they became a standard product. Over the course of several years other transimpedance amplifiers were introduced, all powered by those dammable mercury batteries. The 12 volt mercury batteries were hard to find in stock from suppliers even then (long before the ban) because there was little demand for such a battery. Further, if the amplifier was accidently left on the batteries would be dead next time one wanted to use it. Now remember it was hard to find that special 12 volt mercury battery and that the pair would cost $25 + shipping! (And they could have designed the units to use two readily available 9 volt transistor radio batteries.)

Many potential customers just wanted to measure light and usually they had little electronic knowledge. But they would find out about United Detector and request a catalog. Then they would receivde a bundle of 20 to 30 individual detector data sheets and the data sheets for the five transimpedance ampliers. Here is a biolgist or industrial enginner faced with the problem of selecting the right detector, then choosing the right amplifier, when all he wanted to do is measure some light. What he needed is a *light transducer*, a pre-engineered product just like a force transducer, a pressure transducer or a position transducer.

This was just about the time that the photographic product distributer Ponder and Best (they sold their products under the band name Vivitar), was branding and selling rather mediocre electronic flash units either manufactured in either Germany, Taiwan or Japan. With the varying suppliers there was no consistent product image (that is the designs varied year to year as they changed suppliers or the suppliers changed their products). Then they got smart and designed their own electronic fash unit. It took a few design iterations and released products before they finally got it right with the Vivitar 273 Electronic Flash.

Of course it was an "automatic" electronic flash. Automatic electronic flash units that measured the light reflected from the subject were already common, but most of them quenched the flash by shorting out the capacitor with a transistor when the sensing photodiode indicated that the film had received enough light for correctly exposed negatives. Of course this dumping of the capacitors charge meant that the capacitor charging circuit had to fully recharge the empty capacitor after each shot. Thyristor controlled flashes were just then being introduced. Instead of dumping the capacitor's charge they disconnected the capacitor from the flash tube, retaining the remaining charge for the next shot. So the Vivitar 273 had a thyristor control circuit. Then they designed a small battery holder that held four AA alkaline batteries or four AA NiCad batteries. To further improve this they introduced their own battery pack, containing four AA NiCads and a one-hour charger for this battery pack. Later models had the flash units head's lens mounted so it could telescope thus provide a wide or narrow field of light for wide angle or moderate telephoto lenses. And the added the capability of attaching color filters .. but I am getting ahead of myself and off the point of this entry.
Then they took the final step, they introduced the Vivitar 283 Electronic flash that had the photodetector sensor mounted in a small removable cartridge so that it could be separated from the flash unit itself and reconnected to the flash unit by an extension cable. The sensor would be mounted in the camera's hot shoe while the flash was positioned away from the camera to avoid the dreadful flat lighting that on-camera flash produces.
(As an aside note the Vivitar 285 is still in production and is the premier generic electronic flash unit to this day, having only been superseded by dedicated flash units made by digital camera makers that interact in many complicated ways with their digital cameras. That gives Vivitar's 273, 283 and 285 flash product line a market life approaching 40 years! That is what doing it right accomplishes.)
All of this gave me the idea of creating a light transducer with a removeable photodector that could be connected to the amplifier box by an extension cable. This transducer would be powered by a separate dual +/- 15 volt supply that ran on 120 VAC. All United Detector's amplifiers had a 1X - 10 X

gain changing SPDT switch that swapped the feedback resistors of the transimpedance opamp. This worked well with the 741 but the higher priced high gain ampliers had an opamp that would destroy itself if the feedback path was opened while it was powered up. There was no interlock to prevent this (a DPDT switch with a center off position might have eliminated this problem!). So in a careless moment an amplifier costing $200 could be instantly destroyed! So in my design the value of the feedback resistor would be changed by switching resistors to connect them in *parallel* with the highest value feedback resistor. No more open feedback paths!

So I suggested to the management they develop this product. I even coined a name for the product, PHOTAMP (PHOTon AMPlifier). (Always all CAPS.) Fortunately they weren't interested and two years later I started my own company manufacturing light transducers. Company name: PHOTAMP. Product name: PHOTAMP. (Google "photamp" to see the product.)

I did all the design work for the product: circuit design, schematic, parts selection, double-sided PC board design, the mechanical design of the machined housing and the design of the anodized aluminum name plate that became the top cover. I also did the graphic design for my letter head, envelopes and product data sheet.
I already knew that the retail price of a product had to be four or five times the raw cost of labor and materials. At that time the parts cost was about $50 and it took one hour of my time to assemble and test a PHOTAMP. So I priced my basic Model A light transducer at $274.
I conceived PHOTAMP as a complete system solution for the user. Thus I designed three different mounting plates, a shade tube for the detector, a concentrating lens assembly, and dual +/- 15 volt DC power supply. . Besides the basic Model A transducer the was an AH model with all the gains multiplied by ten, a F model with a SMA fiber optic connector, a PH model with near photoptic spectral response, an A-UV Model with a quartz windowed photodetector processed for enhanced spectral response in the blue and near ultraviot portions of the spectrum. Finally there was the A-BNC Model with a BNC connector to be used with a mating BNC equipped detector and a BNC coaxial cable.
This demonstrates I have an eye for opportunities and the ability to design, produce and market a product.
>> I advertised PHOTAMP in the two controlled circulation magazines aimed at the optical market. I would run 1/6 page ads, the smallest available size, for $400 per insertion. The headline was, "From Your Beam of Light to 0 to 10 volts in one easy step". The ads carefully designed to included sufficent technical information and the *price* so a PHOTAMP could be ordered directly from the ad without waiting for a catalog, data sheets and a price list to arrive by mail. (This was in 1972, long before the World Wide Web.)

My first order was from the Oak Ridge National Laoratory, placed by a purchasing agent over the phone. Others also ordered from the ad and I received many bingo card requests for literature. In less than two weeks another order from the Lab for two more units, followed weeks later by an order for four more. At this point I asked the purchasing agent to transfer me to the ordering engineer. I introduced myself as the founder of PHOTAMP and asked him why he was buying my light transducers. He said had been building his own but that mine were had superior design and cost far less than his cost for in-house fabrication.

Every month or so I would get a printout from the magazines indicating for each advertisement how many readers had requested more information by circling numbers on the reader response card. With my 1/6 page ad I was always the one with the most reader requests. I think there were two reasons for this: my product was unique and thus of interest and the readers of technical magazines scan every advertisement and if something is interesting they circle the number on the reader response card. There was another reason for the high response rate, the PHOTAMP light transducer was the only such transducer on the market. After several months of sales I realized why. My customer base was unusually diverse. I am now quite sure that a formal market survey would not discover much of a market for a general purpose light transducer, thus no other companies have entered this niche market.
>> While working for Boller & Chivens, a small company that designed and manufactured large astronomical telescopes (16 inch to 60 inch apertures), I designed the complete electrical control system for their "standard" 40 inch reflecting telescope. This was long before high powered AC servo motors and servo amplifiers made it possible for a single motor to drive a telescope with a friction roller against a wide disk directly connected to the telescope axis. Back then the axis drives of a telescope had large precision worm gears and complex gear trains with numerous differential gear sets and electrically activated brakes.
At that time all large astronomical telescopes had equaltorial mounts. One of the telescope's two axes of rotation was parallel to the Earth's axis of rotation. As the Earth turned the telescope would be turned in the opposite direction to stay pointed at a star. Right Ascension is measure of rotation about that *polar* axis. The Right Acsension gear was made with extra care and lapped to provide a precise and uniform drive so that the telescope would track stars precisely. The telescope would be driven in Rigth Acsension by four different AC motors and in Declination by three different AC motors.

For Right Acsension (the axis with the clock drive to follow the stars with an equatorially mounted telescope) there was a **slew** three phase AC induction motor, a **set** three phase AC induction motor and a **tracking** (or clock) synchronous AC motor with a a huge gear reduction and 344 tooth to 365 tooth gear set to convert the solar time based 60 cycle drive to the sidereal drive rate. Finally on the Right Ascension drive there was a **guide** motor, small reversible AC capacitor motor controlled by buttons on the astromeners paddle to provide the continuous small corrections to provide fine guiding.
On the Declinaion axis there was a **slew** three phase AC induction motor, a **set** three phase AC induction motor and a **guide** motor to make small

adjustments in the telescopes position to correct any tracking errors.

On both the Right Ascenson and Declination axes these motors were interconnected by differential gear sets and solenoid released brakes. The brakes where necessary to prevent back driving a motor through the differential when it was turned off. (So much complication and expense was eliminated once two servo motors could replace these complicated drive systems.)

The control systen I designed had two layers of relays. The first layer was directly operated by the telescope console push buttons. This layer provided the logic and safety interlock functions. Their output drove the large three phase output contactors that switched the power to the various motors. After drawing the schematic for this control system I designed the many 19" rack panels (about 20 of them as I recall it now) that held the relays and their terminal strips. Then I created the wiring diagrams to connect everything as indicated by the original electrical system schematic diagram. Altogether a complex job that required detailed attention and accurate execution.

After completing that project I left Boller & Chivens. Returning there seven years later I found they were still building the 40 inch reflecting telescopes to my original circuit design without any alteration.

Boller and Chivens was later bought by Perkin and Elmer.

>> One of the problems with the Right Acsension tracking drive is that due to atmospheric refraction as the telescope moved near the horizon the tracking speed needed to be slightly faster or slower than then theoretical sideral rate. Again this was before frequency shifting circuits or servo velocity controlled motors were readily available. I was familiar with the ball disk integrator manufactured by Librascoope that could be used as an infinitely variable speed drive transmission when directly connected to the Right Acsension AC synchronous motor. The gear reduction ratio is so great, from 3600 RPM motor to the once a day rotation about the telescopes polar axis, that a 1/10 HP motor can be used for this clock drive. Thus the ball disk intregrator, originally intended for use in mechanical analog computers to do integration, had sufficent torque drive capability to drive a telescope weighing many tons.

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A brief tutorial about ball disk integrators:

The ball disk integrator has a hardened steel cylinder and a hardened steel disk. The cylinder's axis was at right angles to the disk's axis and the disk's axis is exactly centered over the cylinder's axis. Visualise a horizontal corm cob with a (flat) dinner plate above it. Now add a roller with its axis parallel to the corn cob's axis resting on top of the corn cob. Then lower your dinner plate until it is resting on the roller. When the corn cob rotates it will in turn drive the roller and the roller will turn the disk. Now turn thing around; let's drive the disk at a constant speed. If the roller is near the center of the disk it will be turned slowly and the cylinder will also be turned slowly. If the roller is moved toward the edge of the disk it will be turned faster and the cylinderwill also be turned faster. Thus this contraption can be used as a variable speed transmission.

Except that there is one little problem. To avoid having this variable spped transmission slip there has to be enough pressure on the roller between the

cylinder and disk so it cannot slip. But to change the speed the the roller has to slip sideways along the length of the cylinder. This problem was cleverly solved by replacing the roller with two ball bearings stacked on top of each other in a "tightly" fitting tube that "cages" the two balls. The clearance between the balls and the inner diameter of this caging tube is just sufficient to provide a sliding fit. Again everything is pressed tightly together from top (disk) to bottom (cylinder). The disk presses down on the upper ball, the upper ball presses on the lower ball and the lower ball presses on the the cylinder. Now as the disk rotates it turns the top ball about an axis parallel to the axis of the cylinder. The lower ball rotates the opposite direction but again its axis of rotation is parallel to the cylinder's axis and it in turn turns the cylinder about its axis. (Watching this work in your mind you will notice by replacing the roller with two stacked balls we have reversed the direction of the cylinder's rotation. But nevernomind, we'll compensate for that reversal when we design it into the complete system.) Now suppose you stop the disk and then move the ball cage along the axis of the cylinder to change the ratio of this variable speed transmission. Watching the balls you will see if you move the cylinder to the left the top ball will rotate clockwise, forcing the lower ball to rotate counterclockwise. Thus we can change the ratio without and slipping. So the little problem has been solved.
Some final notes in this side bar about using the ball dik intergator in a mechanical analogue computer:

To use the ball disk integrator as an *intergrater* you drive the top disk with one function and drive the position of the ball cage with the other one. For example to integrate a function with respect to time you drive the disk at a constant speed representing the unvarying passage of time. The position the ball cage to represents the function being integrated with repect to time. The position change of the cylinder during the integration represents the integrated function over that period.

To multiply by a constant quantity let the speed of the disk represent the multiplicand and the position of the ball cage the multiplier. The speed of the output shaft is the product. To multiply by one you position the ball cage that the circumference of the circle defined by the point on the disk where the upper ball touches the disk is equal to the circumference of the cylinder. The circular speed of the cylinder will match the circular speed of the disk.

Now move the ball cage towards the center of the disk. Then you are multipling by a number less than one. At the center the balls will not move and the cylinder will also be stationary, you are multiplying by zero. Move beyond the center and the cylinder rotates in the opposite direction. So we can now multiply by positive or negative numbers and get the correct answer. Now, can we also use it as a divider? Since division is the inverse of multiplication let's see what happens if we interchange the inputs and outputs. We drive the cylinder at a constant speed. When we position the ball cage at the *multiply by one position* the disk is rotating at the cyinder's speed divided by one! Move the ball cage twice as far from the center of the disk and the disk will be rotating at half the cylinder's speed indicating that we dividing by two. Now comes the interesting part. Move the ball cage inside the multiply by one position and we are dividing by a fractional value that is less than one and the disk rotates faster than the cylinder. Keep going closer to the center and the disk goes faster and faster. Approaching an infinite speed as the divisor approaches zero. But when the ball cage reaches zero the disk stops. As we pass zero the disk instantly approaches an infinite speed in the *opposite direction* !! This boggles my mind. Does it boggle yours? This reminds me of the tangent function as it approaches 90 degrees and then passes into the second quadrant. Its value jumps from a value approaching infinity in the positive directon, becomes undefined at 90 degrees and then suddenly pops up near negative infinity.

Now back to our dividing machine and its relation to pencil and paper division. Divide any number by a positive number very close to zero and you get a huge positive number as the answer. Divide any positive number by a negative number very close to zero and you get a huge negative number as an answer. Now back to our mechanical dividing machine. Remember we said *no slipping permitted*. Further, unconsciously, we assumed that the force driving the cylinder always had sufficent power to maintain a constant speed no matter what the load. But when the ball cage is centered on the disk the balls can't move, but our definition says they can't slip. So we have some sort of a singularity. If I built the machine we are discussing the disk would speed up as the ball cage approached zero, but somewhere near zero, even with the most perfect machine that I could build, the output disk would slow and then erratically jiggle back and forth. Because our real ball don't have a single point comtact with the disk but rather a circle of possible contacts. And at times different parts of that circle of contact would make stronger contact turning the disk one way. Moments later other points of contact will turn the disk the other way.

Back to the tangent function as it crosses over 90 degrees. Tangent is defined as TOA   Tangent = Opposite/Adjacent. As the angle approaches 90 degrees the length of the opposite side of the triangle is increasing but asymtopically approaching one. An the same time the length of the adjacent side is decreasing and approaching zero. When the length of the adjacent side equals zero (angle equals 90 degrees) tangent is undefined. So in bringing up the tangent's behavior about 90 degrees and I am really just talking about dividing by numbers as they approach zero from the positive side, reach zero and then cross over zero to the negative side.
To finish: Note that as a multiplier our machine moves through zero with no problem but as a divider it experiences exactly the same problems that occur in "real" division. Interesting, no?.
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Used as a variable speed drive in the telescopes the ball disk integrater was set to multiply by one. Then the ball cage was moved by pulsing a small DC

motor with pushbuttons on the astronomer's paddle to jog the ball cage's position to increase or decrease the tracking speed from the sidereal tracking speed as required to track the stars correctly.

>> There was a special satisfaction to doing astronomical telescope design work . At Boller & hivens we were told: “You are designing a device that will be used for at least one-hundred years, so it must be designed to be maintainable and repairable for that period.”. That was refreshing after having worked in the Los Angeles military/aerospace industry for some years. Once visiting a prominent “war surplus” store in Pasadena, California I found the products of three former employers being pawed over by customers who couldn't have even known their original purpose.

In contrast, some 45 years after the 61 inch Astrometric Telescope was completed at the U. S. Naval Observatory outside Flagstaff, Arizona. I called there and asked to speak to the Director. Connected to him I introduced myself and told him I had worked at Boller & Chivens where I had done the engineering and design work for the Control Console of his Astrometric Telescope. I then asked if I could visit the Observatory a few days later. He was very pleased that I had called and generously extended his invitation. When I arrived a few days later in the early afternoon I was met by the Observatory's electrical engineer. We spent the whole afternoon in a complete tour of the facility. At 5 pm, just before leaving I asked if I could meet the astronomer who would be observing with the 61 inch that night. Meeting him and explaining my connection with the telescope I asked if I could come back that night and watch the telescope in action. He said I would be most welcome, to return at 7 pm, honk my horn and he would let me into the dome.

Those two hours were fascinating. Now the telescope had been fully computerized, though it still had the original complicated multi-motored, differential, solenoid released brake drive system as described above the telescope was now controlled from a comfortable insulated control room that had been built on one side of the dome's floor. There the astonnomer sat at a control console with four computer LCD displays.

The Naval Observatory main task is *astrometry* , measuring the precise position of stars. They do this by observing *parallax*, the apparent motion of relatively nearby stars againt the background of stars that are much farther away. Some of the motion of the nearby stars is caused by the Earth's orbital motion but it is also caused by a star's *proper motion*, its actual movement in the heavens.

The asatronomer had that afternoon entered the complete istructions for that nights work. Of course film has been largely replaced by CCD's (Charge Coupled Detectors) in astronomy and that was true at this observatory as well. One of the screens displayed the current CCD's image, others various control functions.

The computer reponding to its instructions for that night would control thde telescope's various motors to slew to telescope to the correct star field, identify the star desired by refernce to its internal star map and center on that star. It would then automatically guide the telescope to follow that star. The system would the take a trial exposure to determine how long the recording exposure should, measure the current resolution of the telescope (strongly affected by the stability of the atmosphere at that instant), make

the exposure, store the related image and move on to the next star.
Thus we were simply observers. I have a smattering of astronomical knowledge so I asked some questions and we carried on a pleasant conversationfor about two hours.
Altogether at the U. S. Naval Observatory I was treated as both an honored and valued guest. Quite a contrast to visiting a war surplus store in Pasadena.
>> In the past the usual way a mechanical designer tackled a problem like designing chassis of your tractor was to initially create a "light line layout". Unfortunately he is then the only person who understands whart he has designed, it was incomprehensible to anyone else. He might explain his design to others while pointing to various parts of his layout but this certainly cannot be considered a valid design review. Then he would proceed to draw the detail drawings to manufacture the parts, continually referring back to his light line layout for information. While he is creating the detail drawing he will frequently be looking at drawings already completed or return to his light line layout and perhaps add details there to facilitate the progress of his design.
(This is signicant because he is now using several sources of information. For example when designing the front panel he might look at the completed detail drawing of the left panel, the light line layout and the completed detail drawing of the frame. Any discrepancy between these three sources of information will later cause confusion and errors.)
Finally, using the detail part drawings as his guide, he draws the finished assembly drawings. Note carefully: he is now drawing the top assembly drawing by referring to many drawings, maybe five drawings, maybe 20 drawings. Some inconsistencies between these drawings might be discovered while drawing the top assembly drawing but many such incosistencies might easily be missed . (But they would surely be discovered when the prototype is being assembled.) This drawing of the final assembly from the detail drawings was widely regarded as way for the designer to check his work. This was almost the universal way to proceed with design work before computer aided drafting (CAD) was introduced.
While I learned mechanical design long before CAD my mentor insisted that I draw the complete assembly drawing *first*. This drawing even included a complete parts list. Then the design could be discussed and revised with the input of others. *All the the design problems, down to the exact location and specification of the last screw, had to be solved at that stage.* If there was a possible possible mechanical interference (two parts trying to occupy the same space) between parts of the assembly then the auxiliary views that would accurately show the closest approach of such parts had to be included in the assembly drawing.

After the assembly drawing and associated part list were complete and approved the detail drawings would fly off my drafting table like the sheets of a newspaper blowing off a park bench. An A size drawings would take 15 to 30 minutes and larger drawinngs only proportionately longer. Because now the approved assembly drawing provided ONE source of information. *And every design decision had been alreadybeen made and **approved**.*

While I was drawing the detail drawings I always felt that I had a pitcher of complete information and that now I was simply filling individual glasses with that information. With the "light line layout - detail drawings - assembly drawing" work flow the designer was still making "design decisions" while drawing the detail drawings. On one detail drawing he might decide on 1/4-20 fasteners and later when detailing the mating part he might forget the earlier choice and specify 5/16-18 fasteners. Certainly CAD makes the top down design process easier. When one completes the assembly drawing and then simply clipboards the detail drawings from the completed assembly drawing. But even with CAD some designers/draftsmen may still use the "light line layout" method if design discipline is not strictly enforced.

>> The drawing package for a project traditionally includes the top assembly drawing with its parts list and its associated detail drawings. Some of the "detail" drawings might actually be sub-assembly drawings that have their own parts lists and detail drawings. I always add one more drawing to this project package, a *Drawing Tree*. This drawing in a way is similiar to a family tree drawing. The Drawing Tree has the top assembly drawing at the top of the tree. Below that the top Assembly Part List and the Drawing Tree itself are listed. Then come the detail and sub-assembly drawings. Of course each sub-assembly has its own parts list among its detail drawings. This way the valuable information that is usually buried in deep in part lists is brought to the surface in *one easily understood graphic document*, the Drawing Tree.

>> While working for Minimed there was a production problem with their small insulin pump that delivered timed insulin injections through a sub-dermal needle that the patient wore continously. There was "motor" that drove the leadscrew that advanced the plunger in a cylinder to deliver the timed required volume of insulin. I write "motor" because it was actually a small rotary solenoid that advanced a pawl to turn a ratchet wheel. The problem was in the supposed press fit of the ratchet shaft into the ratchet wheel's hub. Both were fabricated from PH17 stainless and both were dimensioned with nominal diameters near 0.0400 inches with +/- 0.0005 tolerances, about the limit possible without seriously increasing their costs. But in some cases the shaft could not be pressed into the wheel and in other cases the shaft would be an easy slip fit into the wheel. I was asked to solve this pressing problem.

At this time the shafts were pressed into the wheels with a small arbor press. Sometimes the shaft would jam when part way in. At this point the shaft had often been bent, scrapping two expensive parts. If the wheel could be pressed in place then the operator would use a Walters Torque Watch to test if the fit was tight enough to resist the required torque. Many failed and the operator would have to press them apart with another press and jig and then noodle about finding pairs that would assemble and meet the torque specificaton.

First I obtained 20 wheels and 20 shafts from the stockroom. I measured the shafts with a precision gage and the hubs with a set of Deltron gage pins. Every part was within the tolerance band specified on their detail drawings. The shafts and hubs were secured to a piece of paper with Scotch tape, their dimension written next to each. Then tried hand assembly. As expected from the recorded dimensions there some part pairs were easily slipped together. I then choose pairs that I expected would result in press fits. I went to the machine shop and using a Hardinge tool room lathe secured the shaft in a collet mounted in the headstock of the lathe. Then I put another collet in the tailstock to provide a pusher for the ratchet wheel. With the tailstock locked down to the lathe's bed I advanced the ratchet wheel using the tailstock lead screw and pressed it onto the shaft. The results were amazing enough to deserve their own paragraph!

In several cases the hub sheared up a chip from the shaft which was curled back as if it had been created with a chisel. But the most amazing, in 3 or 4 examples the hub created a bulge in the shaft rather like the bulge at the end of a green onion. At the moderate force I was applying, surely not as much as even 1000 pounds of force, the hardened stainless steel of the shaft was FLOWING ahead of the ratchet wheel to produce a uniform rounded bulge on the shaft. At this point if you're are not amazed... (I shall stop here!)

(As an aside: The specification for various fits as given in the standard Machinists Handbook are surely accurate and well proven for diameters above 0.125 inches. But they have no idea what they are talking about for fits in the 0.040 inch diameter range.)

I then considered the following solutions: knurling the shaft (tricky to do with a diameter of 0.040" - and you would have to make your own miniature knurling tool), gluing with a Locite product (when tested this was a total failure at these diameters.), electron beam tack welding the shaft to the wheel (we had that capability, but to tie up an electron beam welder for this trivial operation? In addition it would require jigging the parts so many could be welded with one vacuum draw down), TIG arc welding (Would reguire jigging, and a drastically scaled down TIG welding torch and a good deal of testing to see if it would really work. . . . and an operator to make each weld).

After only testing the Loctite solution I rejected all the rest for reasons given. My final solution: *staking*. I considered both radial staking and axial staking and decided on axial staking as the hub was too narrow to imagine successfuly staking it radially. I had a circular punch with an annular hole made up. The punching surface was a ring with a 60 degree included angle. The punch was then hardened and drawn to 6oC Rockwell hardness. It was set up in a hand operated press that worked like a machinists automatic center punch. As the operator lowered the punch and pressed it against the hub a spring would be compressed within the press. At a predetermined point the spring would be released accelerating a mass that provided a controlled impact to the punch. The result was a circular concentric groove in the face of the hub, compressing the hub's metal radially inward against the shaft.

The result gave me another surprise. Many assemblies immediately had adequate torque resistance when tested with the Walters Torque Watch. But in perhaps 2/3 of the assemblies the shaft would turn relatively freely for as much as 1/2 to 3/4 of a turn then suddenly freeze up, far exceeding the required torque in either directon of rotation. I imagine that in these cases galling was occuring at a microscopic scale locking the wheel and shaft together. I sectioned several of these assemblies and the portions of shaft always would instantly separate from portions of the hub so there was no welding. A 40 power binocular microscope didn't reveal any apparent galling.

Over all I considered this a briliantly successful project. I solved the problem without redesigning or modifying the parts. The operator had only select shaft and ratchet wheel pairs that would slide together without force. The staking operation would successfuly join even the loosest fitting parts. The operation of the manual press was as quick and easy as the operation of the simpler arbor press. With the easily done prefitting by hand all the pressed assemblies passed the torque test.
Having just finished the above another even simpler solution suddenly suggested itself. Why not use a similar press to slightly deform a short portion of the shaft back from its end? Then the lower die of the "die set" to do this would have a groove with a stop to accurately position the shaft. The upper die would also have a groove, in this case a rectangular one. The depth of that groove would be such when the faces of the upper and lower dies met the top of that groove would have precisely deformed the shaft. There are two advantages to doing it this way: 1) The die set is simpler and thus easier to make. 2) Without any sharp working edges the die set will have greatly increased life.