A New Innovation in Spline Rolling Rack Tooling

The R/C Rack System is the first major innovation in spline rack tooling since the inception of the process 60 years ago.

By Mike Callesen
THE SPINE ROLLING PROCESS WAS INVENTED BY THE MICHIGAN TOOL COMPANY IN 1954. THE TOOLS USED FOR THE PROCESS, COMMONLY REFERRED TO AS SPINE RACKS, ARE SOLID PIECES OF TOOTHED TOOL STEEL DESIGNED IN SUCH A MANNER AS TO COLD FORM THE APPROPRIATE NUMBER OF EXTERNAL INVOLUTE SPINE TEETH ON A WORK PIECE, TYPICALLY A SHAFT. SPINE RACKS CAN BE REFORMED SEVERAL TIMES OVER THE COURSE OF THEIR LIFE.

The number of regrinds is dependent on several factors, including the pitch, pressure angle, and number of teeth of the spline, severity of damage, and machine parameters. Reforming involves sending the used set of spline racks back to the manufacturer where the old form is completely removed and a new rack form is ground in its place. The resulting difference in rack height is made up by means of a shim that is installed under the rack when it’s re-installed in the customer’s spline rolling machine.

This approach to spline rack tooling created several issues with which the user had to contend. The float of tools had to be managed to ensure there were always racks available when a tool change was required. This involves keeping track of tools out for reform and tracking the logistics of shipping to and from the regrind supplier. Also, due to the fact that it takes roughly twice the time to manufacture new racks as it does to have an existing set reformed, the number of regrinds for each set must be tracked so new tools could be ordered in anticipation of scrapage in the existing float. In an era when most high production facilities use predominantly throw away tools, the tracking requirements can be an onerous task for plant tool management personnel not used to this type of requirement.

The logistics issues became much more acute with the dispersion of manufacturing facilities across the globe. Shipping times that have been measured in days domestically were now measured in weeks. The paperwork and reporting requirements of dealing with customs further complicates the regrind process. In response, spline rack users have had to increase their floats to compensate or risk running out of tools. Spline rack manufacturers have had difficulty becoming truly global suppliers without establishing facilities in each market they wish to participate in, a daunting proposition considering the equipment and technical expertise required for each facility.

From a production standpoint, spline rolling machines have a reputation as reliable, relatively low maintenance pieces of equipment. Their Achilles heel, however, is changeover time. Spline rollers are not designed to be “quick change”. It is typical for tool change time to range from one hour to as much as a complete production shift, depending upon the complexity of the setup and other factors within the production facility. Several spline rolling machine providers have attempted quick change fixtures over the years, but, due to the large separating forces that can be encountered; the success has been sporadic at best.

US Gear Tools, a direct descendant of the original Michigan Tool Company, recognized these problems and endeavored to design a new type of spline rack in order to address them. The goals of the design program were (in order of importance):

- Ensure the same level of quality as is produced from current spline racks.
- Create a “one use” spline rack that could be shipped to any market in the world from our manufacturing facility in the United States, preferably via Fedex or UPS.
- Achieve the same tool life as current spline racks.
- Make the system “quick change” and able to be utilized in existing spline rolling machines anywhere in the world without modification of the machine fixture.

The decision was made to enlist an outside engineering firm to assist in the design process in order to assure the resources would be available to keep the project moving forward. Verstand Engineering of Madison Heights, Michigan was chosen as the design partner. The design had to rigidly and precisely locate the rack inserts in three planes in order to duplicate the performance of a solid set of racks. It was decided that the racks and carriages would utilize matched cross keys to control the primary horizontal location that determines timing of the set. The vertical plane would be controlled by surface ground bearing rails that would be qualified on both carriages after assembly to ensure precise location. The horizontal depth would be controlled by utilizing the area between the bearing rails as a key. The inserts would be clamped by means of four clamping pins (in the case of 24” tools) that would fit into woodruff key slots machined into the inserts.

The design approach was to choose materials and heat treat based on the lowest cost that was considered feasible. Changes that added cost would be made only on the basis of test results. The Alpha prototype was chosen based on an existing spline rack used by a customer close to US Gear Tools Swannanoa, North Carolina facility. The design was reviewed within the company and released for prototype manufacture.

Two phases of testing were scheduled. The initial test was done at US Gear Tools Swannanoa, North Carolina facility. The primary purpose was to evaluate whether the design would duplicate the quality performance of the standard rack. A sample of sixty pieces was spline rolled off of a standard rack then measured for dimension over pins, lead, involute...
and index error to establish the quality baseline. The same machine was then changed over to the new design and another sample of sixty pieces were rolled. These parts were evaluated in the same manner as the first group. There were no changes in the form characteristics of the splines. Further, the capability ratios of each group, based on dimension over pins, were statistically identical. The first goal of the project, no reduction in part quality, was realized.

The carriages were then disassembled and inspected. It was noted that the bearing rails, which take the brunt of the compressive load, had brinelled .0002” in the area where the maximum forces are encountered. This was worrisome after only 60 parts, given that rack life is typically measured in tens of thousands of pieces. It was also noted that because the rack insert was the same length as the carriage, there was not enough clearance to remove it with the carriage in the rack fixture of the machine, negating the goal of a quick change tool.

It was decided to incorporate a design change to slightly shorten the rack insert, thereby allowing it to be installed with the carriage fixtured in the machine. The carriage itself was also modified based of potential fixturing anomalies that could be encountered on individual machines. The Beta prototype was then released for production.

The second phase of testing was performed in the customer’s facility. The Beta tool was set up on a machine in a production line producing 3,500 parts per day. The tool life of standard racks on this line is generally 25,000 to 30,000 pieces. The Beta tool was set up in the presence of USGT personnel.
The part quality was excellent, as expected. After producing 30,000 pieces over the course of the next couple of weeks, the Beta rack was removed by the customer and sent back for evaluation.

The inspection result was surprising. The rack insert showed no appreciable wear or damage. Normally a set of racks at 30,000 pieces would show extensive chipping. It was decided to send the same set back to be run until the life was exhausted. A second set was also included so the customer could perform a changeover. It was also noted that the brinelling issue was still a concern on the carriage bearing rails however; .0004” deformity was observed. The good news was that it didn’t adversely affect part quality, but would continue to be closely monitored.

Upon receipt, the customer elected to put the unused rack insert in. Again, the results were surprising; 56,000+ pieces were produced. This was unheard of for this application. The used insert was reinstalled and ran to 45,000 pieces before several oversize parts were run through it, destroying the racks (but not damaging the carriages). Inspection after these two runs revealed the bearing rail brinelling issue was continuing to degrade, necessitating a design change to a through hardened tool steel.

Several more runs were performed with the new rails, which solved the bearing rail brinelling problem. Tool life continued to be stellar, with one set of inserts reaching 69,000 pieces. The overall average was 57,000, double the existing standard spline rack life. Several more design tweaks were implemented during testing at the suggestion of the customer’s production personnel, such as a screwdriver slot to aid in the removal of the insert from the carriage and tamper proof assembly screws. The documented changeover time was under ten minutes over the course of the test. After 250,000+ parts were produced, the testing was declared over. The four original goals were satisfied.

Once the product development was complete, the focus turned to manufacturing. Standard racks are only green machined and heat treated once, then reground several times. In order for the new rack insert, which must be green machined and heat treated every time, to effectively compete with the existing business model, the insert cost was going have to approach the average use standard rack cost, as denoted by the formula:
New Rack Cost +
(Number of Regrinds x Regrind Cost)
Number of Regrinds + 1

Only by keeping common platform dimensions and mass producing the inserts could this be done. Much effort was exerted to reduce the perishable (insert) cost. Alternate production methods were investigated in hopes of reducing the throughput time without sacrificing the gage level tolerances required. A series of prototype inserts were made utilizing different production methods to evaluate the production cost involved in each. The final process utilized state of the art machining methods never before used in spline rack manufacture that significantly reduced the throughput time. The reduction in set up and processing time brought the insert price down to where, when coupled with the reduction in shipping expenses and machine set up time, made them extremely competitive. The documented increase in tool life, which is fully expected to occur in varying degrees in every application, further enhances the attractiveness to the customer. It is expected that the perishable tool cost per piece will be dramatically reduced, given the additional rack life.

The carriage is considered to be durable tooling. It is engineered to withstand one million cycles before needing rebuild. Many of the wear components are also replaceable in the field. The plan is to allow customers to exchange worn carriages for a “core charge” on the purchase of a new or rebuilt set of carriages. Because all carriages of a given rack length are of the same dimensions, they can be stocked for customer exchange.

Paul Simon, the CEO of US Group, the owner of US Gear Tools, named the tool “The R/C Rack System”. The “R” stands for Roto-Flo, the trade name of the spline rolling machine division of US Group and also the original name given to the spline rolling process by Michigan Tool Company. The “C” was designated for the author of this article. Currently, R/C racks are available in 24” and 13” lengths only. Plans are underway to begin testing a 48” version late in 2014 or early 2015.

The R/C Rack System is the first major innovation in spline rack tooling since the inception of the process 60 years ago. It promises to revolutionize the industry and will provide US Gear Tools access to the global spline rack market from its single manufacturing plant in the United States. US Gear Tools and Roto-Flo will be exhibiting at the IMTS Show in Chicago. A set of R/C Racks will be on display. Please feel free to stop by and see firsthand the next big leap in spline rolling technology.

ABOUT THE AUTHOR

Mike Callesen has been with US Gear Tools/Roto-Flo for over four years, having spent 30 years associated with a competitor in the spline rolling industry. He has been involved with the spline rolling industry for over 34 years. For more information, visit usgeartools.com.