Deep Cryogenic treatment is a supplementary process to the conventional heat treatment for enhancing the mechanical properties of steels. 100Cr6 bearing steel is widely used to make the plunger in the fuel injection pumps of diesel engines. The most perplexing wear problem in the fuel injection pump is concerned with the plunger, as this wear affects the engine performance significantly. Deep cryogenic treatment is the process of cooling a material to extremely low temperatures, soaking the material at that temperature for a prolonged period and then heating it back to room temperature in order to achieve enhanced mechanical and physical properties.

The purpose of this study is to optimise the deep cryogenic treatment process parameters of 100Cr6 bearing steel for hardness, dimensional stability and wear resistance based on the Taguchi method with the grey relational analysis. The deep cryogenic treatment parameters considered for the optimisation are the cooling rate, soaking time, soaking temperature and tempering temperature, with the quality targets of higher hardness, better dimensional stability and maximum wear resistance. The level (value) of the treatment parameters may vary from material to material. In order to identify the optimum values for the treatment parameters, each new material needs to be treated and tested at different levels of temperature, holding time and cooling / heating rate, which is quite tedious because of the large number of experiments. However, the design of experiments (DOE)
provides an optimisation technique to minimize the number of experiments needed.

Preliminary studies were conducted on the 100Cr6 bearing steel samples to analyse the effect of deep cryogenic treatment over conventional heat treatment. Initially a typical DCT cycle was considered. The enhancement of the mechanical properties of deep cryogenically treated 100Cr6 bearing steel was analysed by conducting the hardness test, dimensional stability test, wear test and heat flow characteristics as per the standards. A characterization study was conducted, before and after cryogenic treatment, using the scanning electron microscope, to study the changes in the microstructure, and to identify the mechanism which is responsible for the improvement of the mechanical properties. The preliminary study showed a significant enhancement of the wear resistance, hardness and dimensional stability in deep cryogenic treatment over conventional heat treatment.

The deep cryogenic treatment process was optimised for the best combination of hardness, dimensional stability and wear resistance to achieve the maximum durability. The Grey Taguchi technique was used to arrive at the optimum DCT parameters for 100Cr6 bearing steel. Experiments were carried out, based on the L9\((3^4)\) orthogonal array. To study the significance of the deep cryogenic treatment factors, the percentage of contribution of these factors was evaluated using the analysis of variance (ANOVA). The most influencing factor is found to be the soaking temperature. Based on the optimised DCT cycle, the confirmation experiment was conducted to verify the improvement in mechanical properties of 100Cr6 bearing steel.
The wear resistance was assessed by a reciprocatory friction and wear monitor. The worn surfaces and wear debris, generated during the reciprocating wear test for the conventionally heat treated and optimised deep cryogenically treated samples, were examined using the scanning electron microscope (SEM), in order to identify the operative wear mechanisms in the CHT and optimised DCT samples. The hardness test was carried out by a Vickers’s hardness tester for the conventionally heat treated and deep cryogenically treated samples. The dimensional stability (thermal expansion or contraction) of the conventionally heat treated and deep cryogenically treated samples was measured using a dilatometer. From the present investigation it is observed, that the hardness, dimensional stability and wear resistance of the optimised deep cryogenically treated 100Cr6 bearing steel have improved by 19.35%, 13.77% and 49.02% over the CHT respectively. The microstructure obtained by the SEM reveals that the severity of wear is high in the CHT sample and very low in DCT sample. It was inferred from SEM and optical microscopic analysis that the precipitation of fine carbides dispersed in the tempered martensitic structure; along with the transformation of the retained austenite are the main reasons for the enhancement of the mechanical properties.