Seminar Outline

Gear Materials: Selection, Metallurgy, Heat Treatment, and Quality Control

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Ideally, the design of an optimum gear set requires the coordinated effort of the gear design engineer, the gear metallurgist and the bearing system engineer. The gear is, after all, part of a larger gearbox system thus it cannot be designed in a vacuum. After the basic requirements of the system are met (ratio, operating speeds, shaft orientation, and gear arrangement and tooth configuration, etc.) the system must be "sized" to carry the expected loads (and often unknown, unexpected loads as well). As part of this process, the materials and heat treatment operations to be used for the gears must be selected. In the best case, this is a collaborative effort between the gear design engineer and the gear metallurgist. In the vast majority of cases, however, the material and heat treatment are not so much selected as "stumbled into!" The presenters have designed gear systems as a collaborative effort, together, for more than 40 years. This seminar is our effort to convey both our experience in the process of working as a team and the expertise we have developed for the complete design of geared systems over these many years.

The design and manufacture of any gearing component requires the expertise of many disciplines. Characteristically, design and stress engineers have the greatest input. In many cases, the metallurgist/metallurgical engineer is not part of the process until the part is off the drawing board and ready to be placed into the heat treat furnace. The metallurgist's responsibility is crucial at this point, because the component is nearly 80% complete and very close to the shipping dock. His task is to make the chunk of machined steel turn into a fully functioning component ready for service. As such, there is little room for error. To scrap a part at this point is disaster in the processing timeline. Yet up to this point, the metallurgist may have had little to do with the making of the part.

To optimize the manufacturing of the gear, the metallurgist should be involved in the process from the original design to the placement of the finished part into service. What should he do? What are his responsibilities? Where does he fit in? How can he assist in the design and manufacture of these extremely critical and costly parts? The gear design engineer is responsible for the initial selection of material and heat treatment, but the finalization of both material and thermal processing must be a joint effort.

This seminar will answer these questions and will show how the gear design engineer first approaches the problem of material selection and heat treatment technology, as influenced by the performance and life requirements of the gear set, and how the gear metallurgist should participate in and thereby optimize the finalized gear manufacturing process. The seminar will also enhance the ability of both the gear design engineer and the gear metallurgist to better grasp their relative, related critical roles in the exciting world of gear processing, heat treatment and inspection. Interspersed in the course will be examples of gear-related problems, failures and improved processing procedures. Analyses and comments on a number of relevant failures will be given. Questions, comments and anecdotes of related experiences by attendees will be encouraged. While we will address a range of heat treatment processes in the general sense, since carburized gears are used in a great many critical applications, we will address this processing methodology, in particular, in great detail. Some of the topics to be discussed are:

1. Initial gear material selection – What are the advantages and disadvantages of the various gear material choices, including steel, cast iron, ductile iron, plastics, bronze and more exotic choices?
2. Heat treatment processes and their relation to gear performance, cost, reliability and load characteristics – Through hardening before and after tooth cutting, nitriding, various types of induction hardening (including coil, tooth-by-tooth, dual and multiple frequency) carbo-nitriding and various types of carburizing will be addressed in order to relate the properties obtained to the needs of the gear system.
3. Engineering drawing development – The best material selection process is only as good as the engineering drawing's ability to define and control the process in an unambiguous, clear and complete manner. The need for certification of material properties, heat treatment results and quality control of the overall process will be addressed using examples of proper drawing practice.
4. Review of the engineering drawing – what should the metallurgist look for – five important areas – material, part configuration, heat treat requirements, surface finish technique and quality control requirements.
5. Understanding melt processing – types and quality level – effects of various elements, such as sulfur and phosphorus – hydrogen content, inclusion content, work ratio, normalizing, residual stress considerations. Inspection techniques and advantages – ultrasonic and magnetic particle.
6. Gear materials – their nomenclature, what makes steel steel, effects of the elements, is stainless really stainless? Typical heat treatment processing technique for gear materials.
7. What is carburizing? How does it occur? Comparison of various processes, how to optimize the cycle. What is stress relieving, hardening, quenching, tempering and deep freezing? Enhancements, such as methods to control distortion, intergranular oxidation (IGO) and decarburization.

8. Why the metallurgist should review of the manufacturing process sequence – what he should look for. What about the welding process used for big parts? Review of the heat treat configuration of the part – what is important at this point in the cycle? When and when not to inspect. What about corrosion – can it occur in the shop? How can it be prevented?
9. The metallurgical review of the heat treat facility and the laboratory. The type of furnace, the carburizing atmosphere and its control should be understood. How to inspect and ensure that uniformity of both temperature and carburizing gases are maintained during the heat treat cycle. Circulation pattern of gases in the furnace – is it optimal? What equipment is needed in every metallurgical laboratory from a test sample standpoint?
10. Control of the heat treat process during the actual cycle. How does the metallurgist ensure effective carburizing will occur? The use of test slugs, their size and placement. Where and how does distortion occur? What about decarburization, intergranular oxidation, temper embrittlement. The heat treat procedure should be understood to minimize there.
11. Metallurgical heat treat test sample preparation and evaluation techniques to ensure the data is relevant to the actual parts. Sample and preparation techniques. What to do and not to do. What to look for – intergranular oxidation (IGO) causes and effects, decarburization, retained austenite, how much is OK, etc. Microhardness evaluations and their comparison to the microstructure observed can be used to denote the effectiveness of the overall carburizing process. What about carbides? Are they bad or good?
12. Final inspection and finishing of the gear – This section will include a discussion on the types of grinding burns and how to prevent them from occurring. Other inspection techniques, such as magnetic particle, ultrasonic and eddy current, will be detailed. Finally, shot peening, the process and its benefits will be discussed.

In addition, the following will be reviewed:

1. Videos of the manufacture and heat treatment of an aerospace spiral bevel gear – process controls of the gear from forging to finish grinding and of the multiple frequency induction hardening process will be presented.
2. Hydrogen embrittlement failure of a large gear. – What steps can be taken to eliminate this mode of failure!
3. Quench crack of a large acme threaded worm gear. – These type defects can be prevented.
4. Failure of a helical gear tooth due to an exogenous inclusion – Where and how does this type defect get into the steel? Are some inclusions good?
5. Case core separation, tooth tip cracking – how to prevent this type of failure from occurring.

Who should attend this seminar?

While the subject matter is wide ranging and rather in-depth, the overall level of the seminar is constructed and presented at a level such that the content will be valuable to individuals with a rather broad range of interests, including:

1. Gear design engineers and management involved with the design and manufacture of gearing type components.
2. Metallurgists and materials engineers who want to learn more about gear materials, their processing, heat treatment and control.
3. Laboratory technicians who want to gain a deeper, more relevant understanding of gear heat treating and how to optimize their evaluation techniques.
4. Quality assurance engineers involved with the inspection of gears.
5. Furnace design engineers wishing to become more familiar with the heat treatment of gears.
6. Equipment suppliers wishing to understand gear process technology.