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GD&T Course Rationale for Technical and Non-Technical Disciplines

Technical and business challenges are being influenced by tighter mechanical design tolerances, which is highlighting the critical need for higher precision and confidence in mechanical design specifications and awareness of implications to manufacturing and metrology at all levels.

The following information was put together to aid all management levels in determining which GD&T (Geometric Dimensioning and Tolerancing) and measurement courses are essential for each technical and non-technical discipline including managers and executives. In addition, the information provided will provide historical information to solidify the rationale for each of the courses and provide future direction to managers to establish the appropriate training progression path and certification guidelines for each of their employees.

The following is a comprehensive approach to mechanical competency in 7 seminars covering all aspects of GD&T. A supporting matrix details applicability of each course and recommended educational tracks to achieve mechanical proficiency by job function.

Seminar #	Hours	Class Name
1	4	Business Overview of GD&T & Understanding Business Implications
2	8	Mechanical Drawing Interpretation (Basic Blueprint Reading)
3	16	GD&T Introduction & Fundamental Principles (Interpretation)
4	16	GD&T Advanced Applications (Applications)
5	16	Tolerancing Optimization & Analysis (Analysis)
6	24	Applied Dimensional Metrology
7	16	Measurement Uncertainty

Course # 1 – Executive Overview (Understanding Business Implications of GD&T)

- **Course Length:** 4 Hours
- **Objectives:** To provide business level insight to all management levels of the technical challenges and business level implications of GD&T and measurement. To establish a core foundational understanding of the scope of GD&T applicability to all departments/divisions within area of responsibility. To provide direct insight to the implications effective GD&T has on improving product development cycles and customer/supplier relationships.
- **Targeted Audience:** All managers and executives with direct or indirect responsibility for product development, manufacturing, quality, customer interaction or supply chain management.
- **Prerequisites:** None
- **Historical Challenges:** Most managers have lacked the foundational knowledge in GD&T and measurement and have lacked a core understanding of the business implications these subjects have on product development timelines and supplier/customer interactions. The incorrect assumption by most managers is that all of their applicable employees have the necessary skill sets to adequately perform their job tasks at an adequate level. The key question to all managers should be “where and how would their employees have acquired these fundamental skill sets?” GD&T and measurement are not subjects taught at most universities and colleges and are not focus subjects in mechanical engineering (ME) programs. At best the ME is barely introduced to GD&T and even less on measurement. If the ME is not getting adequately trained then how would we expect any of the other engineering disciplines to get it? If the engineers are not getting trained then where and how are the remaining disciplines being adequately trained (technicians, tool makers, drafters, designers, quality, statisticians, etc)?

Course # 2 - Introduction to Mechanical Drawings

- **Course Length:** 8 Hours
- **Objective:** To understand the 2D & 3D graphical representation of a mechanical drawing or mechanical sketches which includes multiple views, symbols and other drawing details
- **Targeted Audience:** Any individual, including engineering and non-engineering managers who participate in design reviews or technical meetings within the company or with mechanical component and assembly suppliers. Any individual who needs to understand 2D & 3D graphical representation of engineering drawings and sketches. Non mechanical engineers (electrical, chemical, industrial, regulatory, etc.), machine/equipment operators and technicians, assembly personnel, administrative assistants to technical groups, technical sales and purchasing representatives who deal with mechanical components and assemblies.
- **Prerequisites:** None
- **Historical Challenges:** Many individuals who have attended the next level course (GD&T Introduction & Fundamental Principles) could have benefited greatly from attending this course first as many of them did not have a basic understanding of engineering drawing principles. Many of the individuals were technicians across multiple disciplines as well as non-mechanical engineers such as chemical, electrical, industrial and other core disciplines. Most managers are under the impression their employees already know how to read a print but again where would they have learned it? Even in manufacturing and inspection we find most managers feel one of the first things they should teach their employee is how to program a piece of equipment. The challenge with this perception is how would we expect any individual to gain proficiency in programming if they do not even know how to interpret the drawing that are suppose to be making or inspecting the part to?

Course # 3 - GD&T Introduction & Fundamental Principles (Interpretation)

- **Course Length:** 16 Hours
- **Objective:** To provide a foundational understanding (interpretation) of mechanical drawings using linear tolerancing and GD&T in the design, manufacture and inspection of parts, which have geometric controls applied per ANSI/ASME or other national standards.
- **Targeted Audience:** Any individual who must have the ability to "interpret" mechanical drawings using linear tolerancing and GD&T. Any manager with direct or indirect responsibility for product development, manufacturing, quality, customer interaction or supply chain management. Engineers of all technical disciplines, mechanical designers & drafters, mechanical inspectors & technicians, metrologists, machine operators, tool makers and statisticians who analyze data from mechanical components.
- **Prerequisites:** Introduction to Mechanical Drawings
- **Historical Challenges:** Many individuals who had taken a GD&T course previously in their career feel they already have the fundamental skill sets to move directly into the "GD&T Advanced Applications" class. The major problem with this path is that ~95% of the individuals have not applied GD&T since they took the previous class, were taught to a previous version of the standard, or were taught less than optimum methods. In most instances the individuals that have attempted to apply GD&T in some manner have done it incorrectly which has caused parts to be rejected that actually still work or parts to be accepted that actually will not work. Even those that feel they were proficient in GD&T have been more than surprised at the depth of knowledge they did not have on the subject and that many things they were previously doing wrong. One of the most significant surprises is the awareness of how the seemingly complex subject of GD&T can be simplified and how 14 geometric symbols mathematically reduce down to 3. One concern the majority of the individuals have coming out of this course is having to go back to their jobs and work with people within the same disciplines that do not have the same level of understanding of this subject. A second concern is how much time they have to wait until they can get into the next-level courses such as the "GD&T Advanced Applications" course and the "Applied Dimensional Metrology" course.

Course # 4 - GD&T Advanced Applications (Applications)

- **Course Length:** 16 Hours
- **Objective:** To provide applied working knowledge of advanced GD&T applications involving optimization strategies for given design applications, manufacturing methodologies and measurement planning.
- **Targeted Audience:** Anyone requiring a greater understanding of GD&T from an advanced applications perspective. Specifiers and decision makers of engineering requirements and specifications as well as specifiers of manufacturing processes, measurement applications and statistical analysis. Engineers, designers, metrologists, technicians, machinists, toolmakers, senior inspectors, senior technicians, statisticians and mechanical engineers at all levels.
- **Prerequisites:** GD&T Introduction & Fundamental Principles or equivalent knowledge. It is critical that each individual reviews the course content from the introductory course to ensure a positive level of proficiency in all areas. If not proficient, it is highly recommended that all individuals take or retake the introductory course prior to the advanced course to ensure an optimum and proficient level of understanding.
- **Historical Challenges:** Most managers have not made this course mandatory for all the applicable technical and analytical disciplines which continue to be a recognizable problem. Mechanical designers who have attended all of the courses have learned how to optimally represent their functional design intent and have attempted to apply optimized tolerancing to their drawings only to be told to remove the optimized methods by the responsible engineer who has not been taught the advanced methods. In addition, manufacturing and measurement technicians / engineers have also historically not taken this level of course which results in manufacturing claiming the parts will cost more to make and measurement planners claiming the parts are now not inspectable or will cost more to inspect all of which are incorrect. It is not the application of GD&T that's costing more and causing problems, it is the miss-application and miss-interpretation of GD&T that costs more money and continually causes problems. The business implications of all higher-level technical disciplines not learning these advanced applications is growing significantly and is resulting in higher risk to all companies from a product development and product liability perspective.

Course # 5 - Tolerancing Optimization & Analysis (Analysis)

- **Course Length:** 16 Hours
- **Objective:** To apply tolerancing optimization techniques using multiple analytical methods to a wide variety of components and sub-assemblies, from the very simple to the more complex analysis.
- **Targeted Audience:** Anyone with the responsibility of specifying, analyzing and applying tolerances to mechanical components and assemblies, tooling, equipment, fixtures or gages, or anyone requiring a more thorough understanding of tolerancing optimization and analysis. Specifiers and decision makers of engineering requirements and specifications as well as specifiers of manufacturing processes and measurement applications and anyone doing statistical analysis of design, manufacturing or measurement data. Engineers, designers, metrologists, technicians, machinists, toolmakers, designers, senior inspectors, senior technicians, statisticians and mechanical engineers at all levels.
- **Prerequisites:** GD&T "Advanced Applications & Analysis." An advanced knowledge of GD&T is required to allow all participants to be successful in learning tolerancing optimization and tolerance analysis techniques. If not proficient in GD&T at an advanced level it is strongly recommended that all individuals take or retake the advanced course prior to the tolerancing optimization and analysis course to ensure an optimum and proficient level of understanding.
- **Historical Challenges:** One major problem is the perception that this class only applies to design engineers and not the other technical disciplines. Learning GD&T is a progressive task that takes years to become highly proficient and it is essential that all applicable individuals are put on a core training development path that allows ongoing and complimentary learning. It is not uncommon for individuals to take a tolerancing optimization and analysis class prior to them having the core foundational skill sets provided by the previous courses. Individuals attempt to do this because they desire to get information related to how to optimize their callouts, however we will continually fail in this process if individuals do not have core foundational skill sets before hand. In addition, companies will invest into tolerance analysis software packages with the thought that they can simply put their tolerancing scenarios into the software and it will automatically give them the optimum result. The analytical software can only analyze the inputs given so if the information provided is less than optimum it will result in bad information coming out. This results in high uncertainty in the design specification which directly translates in product risk.

Course # 6 – Applied Dimensional Metrology

- **Course Length:** 24 Hours
- **Objective:** To provide fundamental, intermediate and advanced information in applications and analysis of measurement instruments used to determine compliance to mechanical engineering drawings.
- **Targeted Audience:** Anyone requiring a foundational understanding of measurement systems used for measuring mechanical components and assemblies. Specifiers and decision makers of engineering requirements and specifications as well as specifiers of manufacturing processes and measurement applications and anyone doing statistical analysis of design, manufacturing or measurement data. Engineers, designers, metrologists, technicians, machinists, toolmakers, designers, senior inspectors, senior technicians, statisticians and mechanical engineers at all levels.
- **Prerequisites:** GD&T "Advanced Applications & Analysis." An advanced knowledge of GD&T is required to allow all participants to be successful in this class. If not proficient in GD&T at an advanced level it is strongly recommended that all individuals take or retake the advanced course to ensure an optimum and proficient level of understanding.
- **Historical Challenges:** This course was originally motivated and influenced by designers who were being told that what they were putting on a print was not measurable by the inspectors. In addition, the supplier engineers were being told by suppliers and their own inspectors / metrologists that what the designers were putting on a print was not measurable, or that to measure the features as they were defined would take too much time and cost more money. Going on the basis the requirements on the print were valid then the assumptions and accusations were simply not true. When evaluated it was determined that in the majority of the cases the individuals were not trained adequately to correctly interpret the engineering requirement or they were trying to figure out how to check it with an instrument that was not capable to measure it correctly, or both.

  This course is considered a core transformational course that provides direct insight to everyone on 1D, 2D and 3D measurements and also highlights strengths and weaknesses of each instrument in measuring drawing specifications. How does anyone statistically analyze any measurement results if there is insufficient confidence in the measurement method? The implication of the above has the potential of increasing product development and product liability risks. It is essential that everyone measuring parts and everyone on the receiving end of the measured data must have a high confidence the data is correct and they also understand the true level of measurement uncertainty. This course establishes the foundational skill sets required as a prerequisite to the Measurement Uncertainty course.

Course # 7 – Measurement Uncertainty

- **Course Length:** 16 Hours
- **Objectives:** To provide fundamental to Intermediate information in interpretation, application and analysis of measurement uncertainty using multiple measurement instruments and sensors to determine compliance to mechanical drawing requirements. To understand the strengths and weaknesses of the GR&R approach and a total assessment of measurement uncertainty. To understand established "Guidelines for the Evaluation of Dimensional Measurement Uncertainty" (ASME B89.7.2 Standard) in the development of a measurement uncertainty management program.
- **Targeted Audience:** Anyone with the responsibility of establishing measurement procedures and analyzing the implications of various measurement methods and techniques for achieving precision measurements. Inspection planners, specifiers and decision makers of engineering and measurement requirements, specifiers of manufacturing processes and measurement applications and anyone doing statistical analysis of design, manufacturing or measurement data. Engineers, designers, metrologists, technicians, machinists, toolmakers, senior inspectors, senior technicians, statisticians and mechanical engineers at all levels.
- **Prerequisites: "**GD&T Advanced Applications & Analysis" and "Applied Dimensional Metrology" All individuals must have an advanced working knowledge of GD&T and a foundational knowledge of Applied Dimensional Metrology to be successful in this class.
- **Historical Challenges:** The most significant and ongoing problem is that the majority of the companies use "Gage Repeatability & Reproducibility" (GR&R) as their basis for determining if their measurement process is sufficient to the task of measuring features. The policy or basis for good measurement is that if the GR&R results are less then 10% of the specification limits (or potentially 20% or even 30% within some companies) then the measurement is considered acceptable. The core problem is that all measurements have the potential of being repeatably and reproducibly incorrect, which means the person who determined the measurement instrument and method could be inducing an uncorrected bias into the measurement. If the metrologist did not know they were inducing a bias then there would be no way for them to correct for it. A simple and common example is that inspectors will commonly use a 1-dimensional measurement instrument (such as a caliper or micrometer) to measure a 3-dimensional feature(s) on a part without evaluating or guard-banding for the form or other applicable sources that could negatively influence the result.

  This course establishes the foundation for confident measurement results which forms the basis for low risk decisions at all levels. Statistically analyzing highly confident results will significantly reduce product development and product liability risks.