The TTT System – a Window into Tribology

Evaluation of Metal Working Fluids and Tool Properties in Terms of a Real Metal Working Process

The TTT Tapping-Torque-Testsystem is a multiple comparing evaluation system for efficiency ratings of metal working fluids (MWFs) on the one part, and tool properties (material, geometries and coatings on the other. Based on the technology of a torque controlled and process secured thread tapping unit (cutting and forming all kinds of ferrous and non ferrous metals), the process takes place without a lead screw, only following the pitch of its tool.

Fitted with a specialized analysis software and a temperature sensor for the determination of the Delta T value (**ΔT)**, the TTT System identifies and records decisive process-parameters in respect of lubrication, friction and wear and depicts these in the form of sine curves, multicolored bar charts and tables on a connected computer screen. By this means it is possible to provide and interpret the tribologic impacts depending on lubricant formulation techniques, tool properties and work piece materials.

The physical load-parameters at metal working, established by the German Society of Tribology (GfT) in 2002 [1)]**,** which take effect during a friction and wear process, are defined by four values:

Normal force $\mathbf{F_N}$

Speed **v**

Time of load $\mathbf{t_B}$ and

Temperature **T**

Applied within the functions of the TTT System are:

- Normal force $\mathbf{F_N}$ as the calculation basis for the torque at the machine spindle,
- velocity **v** for the speed of the machine spindle, cutting speed
- time of load $\mathbf{t_B}$ for thread depth and time (rpm),
- and temperature **T** for the calculated Delta T **(**Δ**T**) value.

Enabled by its evaluation software the TTT-System measures, records and depicts the following parameters during process and conditions them for advanced analysis:

- **Torque** as a measurement value for the factually generated work performance (Torque Mz Ncm)
- **Mean Value** as a measurement value for the entirely generated work performance in average (arithmetic mean)
- **Standard Deviation** as a measurement value for the mean deviation of torque around the Mean Value (measurement of spread)
- **Gaussian Curvature** as a measurement value for the frequency distribution (statistics) of the number of the various torques during process gives insight into the homogeneity of a lubricant (with 20 mm depth).
- **Integral** as a measurement value for the total load on the measurement tool (wear). Calculated by trapezoidal area computation is the area below the torque curve which allows the numerical approximation to the effective friction value.
- **Temperature value** Delta T (**∆T**) as a measurement value for the thermal impact on the process (caused by e. g. process speed, frictional heat, parts of water, additives, additive families, EPs, work piece materials and tool properties (geometry, coatings)) for the interpretation of tribological effects.

The **Analyzer,** which assesses the computed results according to the aforementioned parameters, has a Dual-Cursor at command, which allows spotting any section of the graphic measurement (e.g. working tableau) and restricts the chosen area for a more detailed examination.

Temperature – a major parameter for the evaluation of lubricants

Temperature in a work process is significantly influenced by work piece material, tool properties, (e.g. geometry, coating), process speed and the hereby influenced torques occurring during process, time of load (depth and cutting speed) and last not least the lubricity of the formulation respectively its formula.
All these features are essential for the determination and interpretation of tribological impacts and are therefore indispensable for a decision in regard of a selection in favor of a certain lubricant respectively its formulation technique.

The temperature difference value ΔT distinctly provides insights on the influence of temperature on tribologically relevant layers (formed by additives) and also, whether and under which conditions tribological layers are formed.
There are many opinions concerning these phenomena, therefore it is crucial to recognize the parameters and conditions under which positive or negative interactions occur – or not.

At the time of the greatest heat build-up however, the exact temperature of the tool can't be measured unless undertaking an enormous effort. In practical application such a procedure would cause almost irresolvable problems.
Yet, when measuring the temperature at the tip of the tool by infrared rays directly before measurement and again right after measurement, both data can be compared. The difference delivers the temperature value Delta T (ΔT). Although not expressible in absolute degree-values according to Celsius, the determined ΔT assessments are still accurate and deliver highly diagnostic values for the interpretation of temperature influences.

Influence of temperature on the formation of reaction layers

As commonly known the temperature-ranges in literature, when additives and EP additives take effect, are not very accurately described; and also, that different additives do not necessarily act synergistically. They also can influence their effective power in a negative way.
In order not to have additives "swimming around" ineffectively or rather harmfully in the formulations, it is necessary to display the mechanical reality and accordingly draw verifiable conclusions.
A particular attention should be directed to temperature respectively frictional heat, which is presupposed to make these processes happen at all.
This means, the compatible ratio of mixture, incl. the proportion of water (cooling factor) also depends on the laboratory parameters, for example speed, on tool coating and last not least on the ingredients of the formulation, for example additive families. Additives, especially EPs, ask for a certain temperature in order to form effective reaction layers.
Even smallest quantifiable differences can have a great influence on tool life, whereby its wear is supposed to be held as small as possible. This means, that the

mechanisms of action depending on the temperature during a real work process and given laboratory conditions have to be precisely observed.
One of these resulting mechanisms of action, for example, is the so called Carry-Over-Effect, which verifiably can appear and has to be considered when in connection with certain temperatures surface-active additives locally form so called reaction-layers during process, for example iron sulphides.
These layers may alter the crystalline structure of surfaces; they alter the local electronic setting and, as a result, enlarge the surface. Here it can be assumed, that (at least) in the moment of functioning they do not sit on top of the tool surface – as often is described in literature – but rather become a surface of its own.

But it’s not only the temperature and the additives of a MWF which cause relevant impacts:
“The kind of interaction depends on the nature of the additives and the chemical nature of the metal surface” says Prof. Dr. Joachim Schulz [2)] of the “Foundation Institute of Materials Science, Bremen, Germany”. In his much-noticed publication “Lubricants” of 2013 he continues with an example: “*Oxides respectively oxidic surfaces (stainless steel, aluminum, titanium) are unable to really interact with ionic additives, like e.g., acidic compounds of phosphorus or overbased sulfonates. These kinds of surfaces interact only with nonionic additives, e.g., chlorinated paraffins or neutral sulfur compounds. The oxidic bond between metal (iron, chromium, or nickel) and oxygen is very stable and cannot be separated by additives in metalworking processes.”*

However, to challenge these aspects is not the task of machine builders but rather the chemists and tribologists.

The main users of the TTT-System are

- National and international oil- and lubricant companies with production facilities (R&D) around the world,
- National and international tool manufacturers who also act cross-border and
- University and industrial laboratories for application oriented research and development, for controlled process secured production engineering in search of new findings and insights into the tribological reality all over the world.

In order to meet all their requirements on the basis of scientific methods it is necessary to provide compatible conditions in regard to material, measurement technique and physical terms.

The TTT-System and its Standards

- Metric system (mm)
- Assessment of power (Ncm)
- Standard speeds (min-1 / rpm)
- Temperature (°C)

Exclusively applied in the TTT-System are gauged tools and materials according to the following standards

Gauged tools

- **TTT_M4F-NT** Forming vaporized nitrated with gauged pitch-diameter
- **TTT_M4F-TINT** Forming TIN coated with gauged pitch-diameter
- **TTT_M4C-T** Cutting-Standard blank with gauged pitch-diameter

Manually proven test bars with 140 blind holes for a thread length of 20 mm (5xD)

- Test bars steel, **X6CrNiMoTi17-12-2 / 1.4571** (V4A) / 316Ti
  Tensile strength R_m 725N/mm² / 225 HB / 112 PSIx1000
  Elongation A_5 (%) > 40 / R_m = 775N/mm²

- Test bars Alu, AlZnMgCu01,5 / 3.4365 / 7075
  Tensile strength Rm 420-450 N/mm² / Rp0,2 = 420 N/mm²
  Elongation A5 > 5-7% / 140 HB / density 2.78 Kg/dm³
  (Aircraft – CarEngine standard/classic)

Standard speed / cutting speed

- Steel 800 min-1
- Aluminum 1200 min-1

For design and evaluation of MWFs it goes conform with the TTT-Standard to use vaporized nitrated measurement tools only as with coated tools chemical incompatibilities and intolerances may occur.
Similar is strongly recommended for design or evaluation of new tools to solely use a clearly identified standard MWF, so that the gained results remain comparable and repeatable elsewhere at any time.

Exclusion method in practical application

When designing a new lubricant or a tool of a different material, geometry or coating, it is highly recommended to employ the so called exclusion method to find out whether a step in development causes positive or negative results.

Lubricant designers have to deal with all kinds of requirements and materials, which always ask for special solutions.

By targeted trying-out different formulation techniques the effects – either positive or negative – will crystallize out.

In order to demonstrate different realities, for example increase or decrease of temperature (as certain additives depend on a certain amount of heat to become effective while others may be destroyed with too much heat), it may be necessary to accelerate or to reduce the process speed.

Further steps are to add or to remove lubricating ingredients, additives, water (or parts of them) or to change the tool, not only because it might be worn, it also should be considered, that a coated tool, contrary to an uncoated one, might show a different performance in combination with certain additives thus transforming a supposed physical problem into a chemical incompatibility- or vice versa. Therefore it is important to execute a conclusive control measurement for every development step and for each single alteration.

Evidence of impact and effect is indispensable which implies that all results must be replicable and repeatable.

The proceeding in this way can not be attributed too much importance, as it might show features which amount to totally new and precious mechanism of action respectively prove chemical intolerances or physical inabilities.
The results of each single alteration will be shown in the TTT analysis.

Is it positive and the altered lubrication sample respectively the altered tool conditions deliver better measurement values, this might be very exciting for every lubricant resp. tool designer.

In all consequences this means, that the criterions occurring during work process, are not only a yardstick for the physical or the chemical proportion of the process but also deliver evidence of the creative share when formulating a new MWF or tool.

Those, who innovatively put themselves into this adventure and want to find out why, by which means and under which conditions a friction becomes smaller or greater – despite equal mechanical efficiency – will benefit from the flexibility and range of the TTT-System (including the new standards and methods); even if due to the enormous complexity of tribologic processes the results are an approximation to absolute values only.

Most often it is the own experience, so to say the empirical evidence, that comes up with a solution of a problem in the contact area of interacting surfaces in relative motion.

The TTT-System helps to better understand and verify the tribological mechanisms of effective power of complex formulations.
It is a device for the generation of economically and hopefully also ecologically successful solutions for the development and optimization of lubricant formulations and also for the design of metal working tools, geometries and coatings in a scientific and industrial context.

1) GFT, Tribologie, 2002, worksheet 7, page 8)

2) Lubricants 2013, S. 84, Joachim Schulz 1
1. "On the Interactions of Additives in Metalworking Fluids with Metal Surfaces"
2. Theoretical Model of the Interactions between Additives and Metal Surfaces
Explanation of (Re)Action of Additives in Metalworking Process (General)

Maximilian Müller
microtap GmbH
TTT-Systems / Thread Tapping Technology
Rotwandweg 4
82024 Taufkirchen / Munich - Germany
Tel +49-172-8557177
www.tapping-torque-test.com
http://TTT.systems
www.microtap.de