Application Condition as a Starting Point of TESE-based Prediction

Aleksey Pinyayev, pinyayev.a@pg.com

Abstract

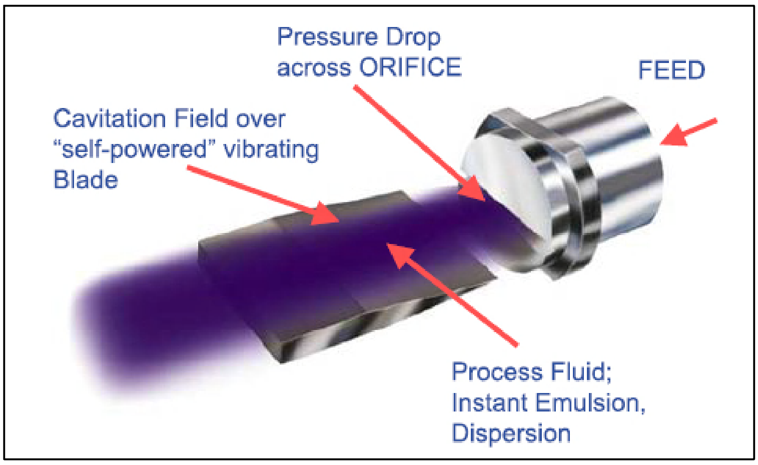
This article suggests the use of the Application Condition of a Functional Clue as the starting point for the prediction of the technical system development based on the Trends of Engineering System Evolution (TESE). It is shown that such use simplifies application of TESE. It also links TESE to the problem definition techniques such as why-why and functional analyses and creates a seamless technical system development workflow. This approach also allows to expand the database of the Functional Clues by distilling the Recommendations from TESE.

Background

In addition to solving problems, an Application Condition of a Functional Clue helps TESE-based prediction. Defining an Application Condition allows to precisely identify a part of a system or supersystem a Trend needs to be applied to. The Application Condition also contains the functional interactions of this part and defines the functional core of the elemental problem which needs to be solved in order to evolve the technical system. In other words, an Application Condition defines the starting point and direction of the technical prognosis. Knowing the part allows to correctly define its position at the evolution curve of the given Trend. The TESE allow then to identify the necessary modification of the part which leads to the next step in the system's development.

As shown in (Pinyayev 2007), the definition of an Application Condition is a result of a workflow which includes the why-why analysis of the inventive situation and definition of an elemental problem in the form of a why-why contradiction. Once a why-why contradiction is identified, an Application Condition definition algorithm must be used (Pinyayev 2010). These steps are essential. In author's experience, trying to guess an Application Condition without completing these necessary steps almost guarantees an incorrect result.

Case Study: Sonolator



Sonolator is a high-shear mixer, homogenizer and emulsifier which works via ultrasonic cavitation created when a high-velocity liquid jet impacts vibrating blade (see figure at the left). The jet is created by passing a pressurized liquid through an orifice. When jet impinges the blade, this blade starts vibrating with a sonic frequency (3 kHz). The cavitation, created by the sudden pressure drop and controlled by the vibration of the blade, thoroughly mixes, homogenizes or emulsifies the liquid.

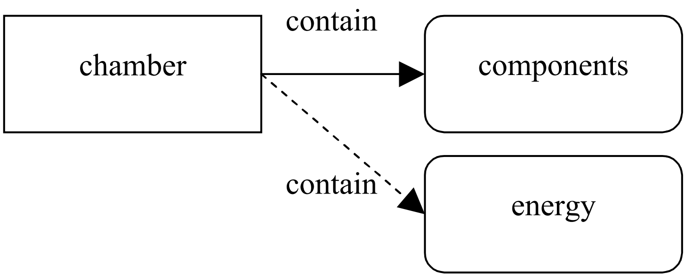
The evolution of the Sonolator will be used to illustrate the main points of the current article. A patent research has been done to reveal important developments of the Sonolator design. Throughout the article, the references to the key patents will be provided.

The Use of Application Conditions for Prediction

The use of an Application Condition for prediction allows to specify the object of prediction, to define this object's attributes and to lay out critical interactions which propel the system's development. There are two ways to use the Application Conditions for prediction: at the level of the entire system or at the level of its subsystems. These ways differ only in the object of prediction. At the system level, the object of prediction is the entire system. The definition of the Application Condition in this case is done via analysis of the supersystem. At the level of subsystems, the analysis of the system is used. The methodology of defining an Application Condition is described in (Pinyayev 2007) and (Pinyayev 2010). Once the Application Condition is defined, TESE can be applied to the objects and interactions the Application Condition consists of. Because the system of the Application Conditions provides a multi-faceted description of the system's "stress points", the Application Condition-based prediction is specific and comprehensive at the same time.

Sonolator Effectiveness Prediction

Sonolator works so well as mixer, homogenizer and emulsifier because it provides much higher specific power than lower-shear mixers. Specific power is the power delivered to the product divided by the active volume of the product. Thanks to the high shear at the orifice, effective interaction of the blade with the product and cavitation, the internal volume of the Sonolator is much smaller than that of other mixers. The mechanical power delivered to the product is high thanks to the high orifice pressure. However, some hard-to-mix products require an order of magnitude higher specific power than a regular Sonolator design can provide. The why-why analysis of this challenge leads to the following why-why contradiction: *How to reduce the active volume without reducing the Sonolator's internal volume?*



This is the Application Condition of this contradiction defined by using algorithms described in (Pinyayev 2010). The TESE need to be applied to the internal chamber of the Sonolator. Since the chamber is a cavity, a Space Segmentation trend would apply. The next step predicted by this trend is system with multiple cavities. The Application Condition prompts that there need to be two different cavities: one for components and one for energy. The existing chamber can be used to contain components, so a new (smaller) cavity needs to be added to contain energy. The practical solution (Fig. 1) is described in (Grange 1978): the energy is contained between the two added

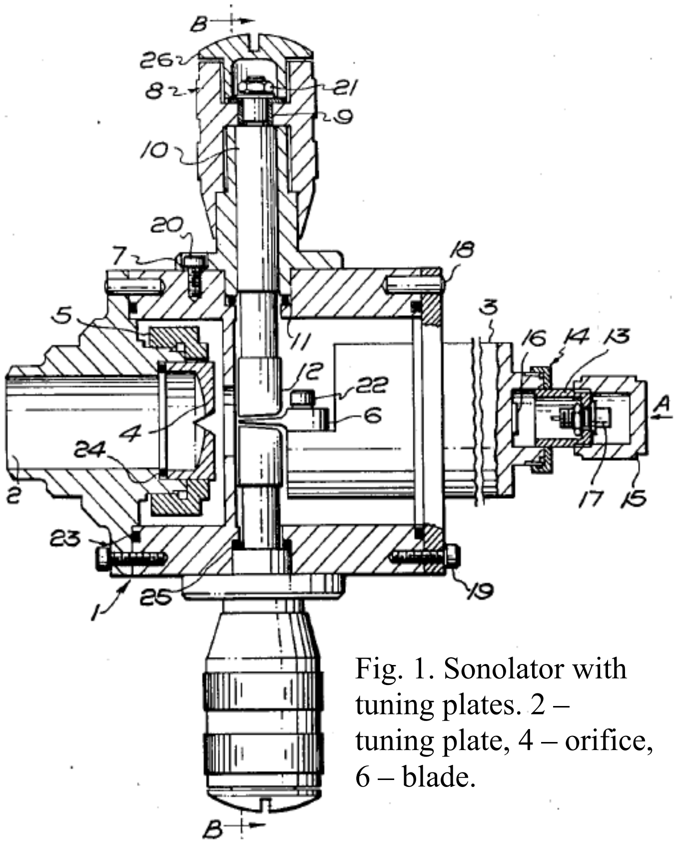
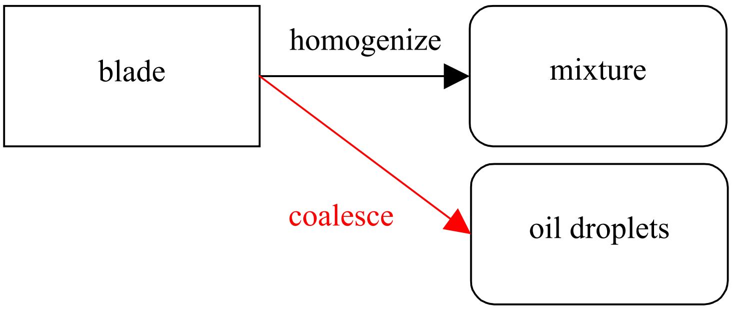


Fig. 1. Sonolator with tuning plates. 2 – tuning plate, 4 – orifice, 6 – blade.

surfaces called tuning plates which are placed in a close proximity to the blade. In addition to increasing the energy density by at least an order of magnitude, the tuning plates are able to optimize this density according to the properties of the product: the development according to the Controllability trend.

Sonolator for Shear-sensitive Fluids

The Sonolator's principle of action inevitably leads to the high shear forces imparted on the mixture to be homogenized. Some mixtures are shear-sensitive and their structure and properties can be negatively affected by the high shear forces. One example of such mixture is a well-known emulsion called mayonnaise. Too much shear applied during mixing various components into mayonnaise can destroy the emulsion by causing oil droplets to coalesce. Another example is a mixture of a liquid with a solid such as long-chain polymer or fibrous material. High shear forces may degrade useful properties of the solid. It is therefore desirable to process shear-sensitive mixtures by a very effective homogenization process similar to that of a Sonolator without applying high shear forces to the product. The why-why analysis of this challenge leads to the following why-why contradiction: *How to effectively homogenize the product without applying high shear forces to it?*



This is the Application Condition of this contradiction defined by using algorithms described in (Pinyayev 2010). The TESE need to be applied to the blade of the Sonolator. According to the Introduction of Modified Substances trend, an internal additive needs to be designed into the blade to eliminate the coalescence keeping effective homogenization. An example of such additive is a weight on a free end of the blade (Fig. 2). Such weight lowers the resonant frequency of the blade. The mass of the weight, length of the blade and distance from the weight to the orifice

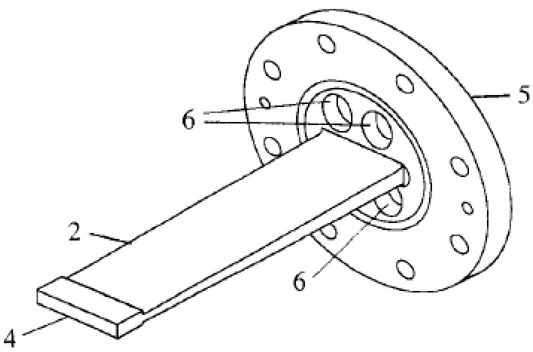
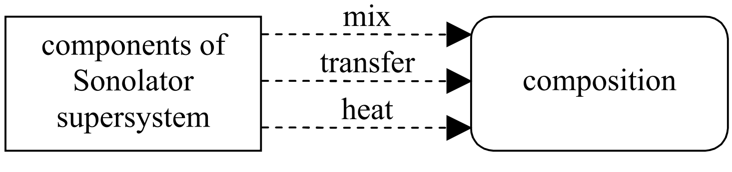


Fig. 2. Weighted blade of the Sonolator. 2 – blade, 4 – weight.

are all selected to provide effective vibration at very low orifice pressure. This way, the modified blade keeps high degree of homogenization by mechanical vibrations and avoids high shear forces. The practical solution is described in (Semp 1999). The new design allowed to uniformly and effectively incorporate a long-chain polymer (polyacrylamide) into water, make stable oil-in-water emulsion, generate foamed adhesive and incorporate guar-gum powder into water – all at orifice pressures below 25 psi (as compared to hundreds and thousands psi for a regular design).

Homogenizer for Viscous Compositions

An example of a prediction at a system level is a Homogenizer for Viscous Compositions. As mentioned earlier, when prediction is done on a system level, the analysis of the supersystem is used in order to define the problem. The supersystem typical for the Sonolator is a liquid processing unit which includes product, feed tanks, pumps, process control instrumentation and plant personnel. A known challenge at this supersystem level is homogenizing multi-component viscous compositions. Such compositions include, for example, mixtures of grain powders or flours with oils and lipids. Another example of such composition is a mixture of toothpaste ingredients. Mixing, transfer and emulsification of such products in a typical Sonolator-based liquid processing unit is difficult. Mixers and pumps typically used with Sonolator are not optimal for handling high-viscosity inhomogeneous compositions. Some of the compositions require relatively high temperatures in order to melt and solubilize components such as lipids and waxes. Heat-jacketing of the entire unit leads to a significant increase of the capital cost. The why-why analysis of this challenge leads to the following why-why contradiction: *How to provide high-pressure liquid input into Sonolator without using typical Sonolator supersystem components?*



This is the Application Condition of this contradiction defined by using algorithms described in (Pinyayev 2010). This Application Condition combines three partial Application Conditions of U2 type, one for each insufficient function. Combining partial Application Conditions into one allows to clearly see that various inefficient pieces of the Sonolator's supersystem are, in fact, a Polysystem in relation to the Mono-Bi-Poly Trend for Various Objects. According to this Trend, the next step in the Polysystem development is the transition to a Combined Polysystem which performs all functions of a simple Polysystem (*mix*, *transfer*, *heat*) by a single piece of equipment. This piece of equipment is known as an extruder, so the new concept suggests feeding the Sonolator directly from an extruder (Fig.3).

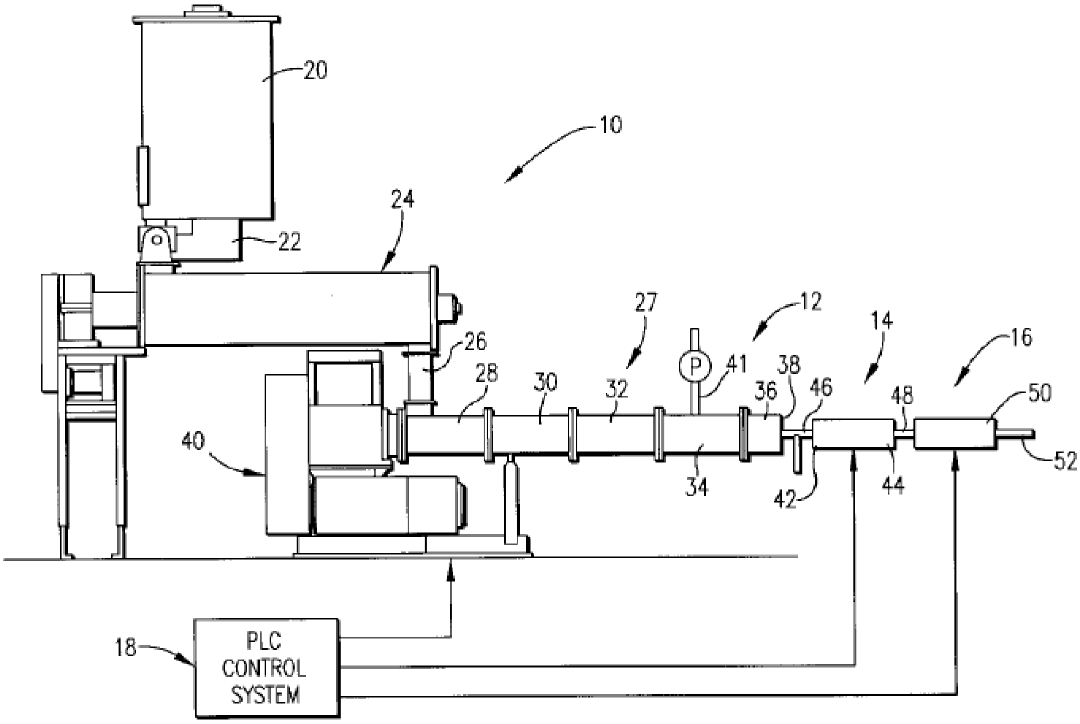


Fig. 3. Homogenizer for Viscous Compositions. 12 – extruder, 14 - Sonolator

This new design (Huber 2001) has multiple advantages when the high-viscosity, multi-component products are processed. One important advantage is that making stable emulsions of such products is possible without the use of emulsifiers since the Sonolator produces emulsions with a very small (micron and submicron) droplet size and the stability of an emulsion is strongly dependent on the droplet size. However, the most important advantage is that Sonolation of the viscous, non-homogeneous, complex products becomes feasible.

Conclusions

The use of an Application Condition as a starting point of the TESE-based prediction allows to define a component which needs to be developed in accordance with the Trends. It also allows to define a conflict that requires resolution in order to move the technical system up the evolutionary curve. This valuable information allows to make prediction focused and targeted and to increase the quality of the prediction concepts.

The workflow which is used to define an Application Condition usually leads to the multiple problem definitions called elemental problems. Each elemental problem solves the primary challenge in its own, unique way. A set of these solutions obtained via TESE allows for a multi-dimensional prediction of the technical system development. This result is an umbrella of the technical concepts which can flexibly adapt to any environment in which the technical system evolves. Depending on the circumstances, some of the concepts are reduced to practice fairly quickly and others become longer-term predictions. This multi-concept prediction approach is much more robust and agile than a stand-alone prediction.

For the complex technical system dominating modern technosphere, the approach described here significantly simplifies the application of TESE. An Application Condition provides a precise definition of the object to which TESE are to be applied. The functional interactions of this object define the direction of the development.

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