

# Automated, Fluorescent Liquid Penetrant Inspection on Serial Workpieces with High Throughput and High Process Reliability

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**Abstract.** In a first example a semi-automated highly flexible system is described which can be used for a broad variety of components. Cast workpieces for power generation in varying sizes and geometries were specified in the duty book. It should be possible to use optionally two fluorescent penetrants of different sensitivity. During the whole inspection process the components are placed in baskets and are pushed manually from station to station. The pneumatic lowering and lifting of the baskets at each station is automated. Each step of the process is started via pushbuttons and is then executed automatically. This ensures the reproducibility of the test results. Because of the broad spectrum and the sometimes only low number of workpieces, the process steps for penetrant removal and developer application are designed as manual stations. This enhances the flexibility of the whole system in view of future workpieces.

The second example describes a fully automated system, optimized for maximum throughput with a high level of automation and low testing costs per workpiece. Stainless steel forgings for the automotive industry shall be tested with high sensitivity for surface cracks. At the loading station the components are placed in workpiece holders that are optimized for the components geometry. Once the workpiece holder is inserted manually the system takes over control of the transport for the entire testing line.

A third example shows a large semi-automated testing system where an oval crane runway is used for the workpiece handling.

## 1. Introduction

This article presents three systems for fluorescent liquid penetrant inspection. All three systems are optimized for high throughput and show a different degree of automation. Normally PT chemicals specified as *Type I, Method A, Form a* in accordance with EN ISO 3452 are used.

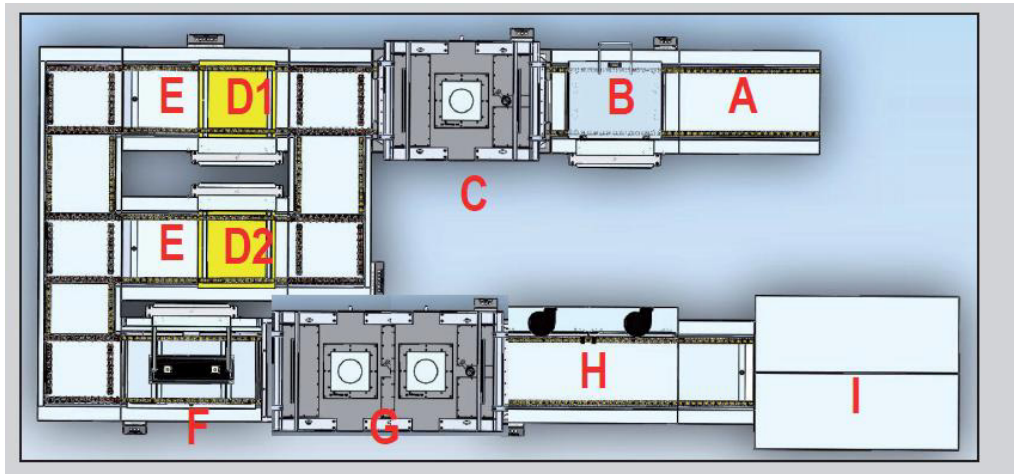
## 2. Semi-Automated Testing of Castings

The first example is a semi-automated system that can flexibly be used with a large variety of workpieces (see fig. 1 und fig. 2). The customer's available workshop space led to a U-shaped system layout. Many different cast workpieces in various sizes and geometries were specified. Components throughput depends on the specific workpiece properties and the respective manual process steps. During the whole inspection process the workpieces are



placed in baskets and are pushed manually via roller tables from station to station. The baskets dimensions are 0.5 m x 0.5 m x 0.12 m and they are designed for an overall weight of 30 kg.

In order to prepare the castings surface for penetrant testing, a pre-cleaning station, consisting of a washing unit and a dryer, is integrated in the system. Pneumatic lowering and lifting of the baskets at each station is automated. Process times (e.g. penetrant dwell time and developing time) are stored and controlled by means of a Siemens PLC. Each step of the process is started via pushbutton and then runs automatically. This guarantees the reproducibility of the test results.



#### **Stations of the system**

- A:** *Component feeding*
- B:** *Pre-cleaning (water bath with additional water nozzles)*
- C:** *Dryer 1*
- D1:** *Penetrant dip tank (level 2, medium sensitivity)*
- D2:** *Penetrant dip tank (level 3, high sensitivity)*
- E:** *Drainage station (one tank per way, penetrant recirculation to the original tank)*
- F:** *Penetrant removal with water and hand-gun  
(after lowering into stainless steel tank and folding out the lateral protection doors)*
- G:** *Dryer 2*
- H:** *Electrostatic developer application (with exhaust in rear, lateral protection doors)*
- I:** *Visual examination under UV light in a testing cabin*

**Fig. 1.** Semi-automated testing system for castings (top view)

It should be possible to use optionally two fluorescent penetrants of different sensitivity. Normally a penetrant with medium sensitivity (level 2) is used. Approx. 10% of the components are tested with a high sensitivity penetrant (level 3).

Because of the broad spectrum and the often only low number of components the process steps penetrant removal and developer application are designed as manual stations. This enhances the flexibility of the whole system also in view of future components. After pneumatic lowering of the basket in a stainless steel tank penetrant removal is done with the aid of a water / compressed air gun. Pressures of water and air are monitored via manometers. The next steps comprise drying, which is carried out in a hot air oven, and electrostatic application of the dry developer. Excessive dry developer is removed by exhaust ventilation. Because of the system's modular design it can be extended easily and therefore prepared for alternative testing tasks.



**Fig. 2.** Testing system for castings, overall view

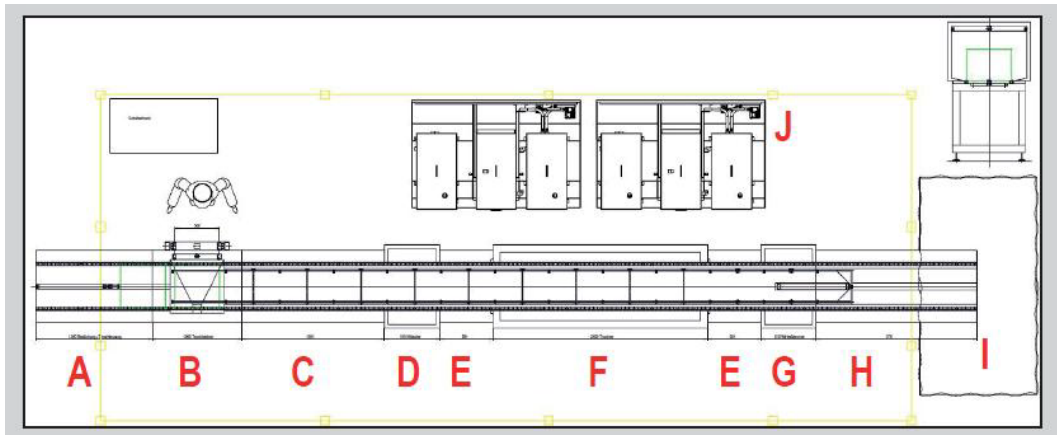
### **3. Fully Automated Testing of Forgings**

The second example, see fig. 3 and fig. 4, is a fully automated system, optimized for maximum throughput with a high level of automation and low testing costs per workpiece. Stainless steel forgings from the automotive industry are to be tested with high reproducibility for surface cracks. All process steps are fully automated. Components are handled in workpiece holders with a capacity of ten pieces and optimized for the workpiece geometry.

It is advantageous that (except for the dipping station) all stations of the newly designed system provide the same working level. This permits the realization of a relatively simple transportation concept avoiding many lowering or lifting operations of the workpiece holders.

A difficulty with fully automated systems are different process times at each station. Furthermore empty workpiece holders must not put at risk the programmed process sequence and thereby the inspection reliability. This is ensured by an optimized layout of the process stations (e.g. washing station, dryer) and a complex process supervision. In this example the workpiece holders are moved from station to station at 3 minute intervals. For longer lasting process steps corresponding buffers are integrated.

After application of the developer the components are transferred to the station for the visual test.



**Stations of the testing system**

- A:** *Component feeding*
- B:** *Penetrant application (pneumatic lowering into dip tank)*
- C:** *Draining station and recirculation of excess penetrant*
- D:** *Penetrant removal via water-jet tunnel*
- E:** *Buffers*
- F:** *Dryer (circulated warm air)*
- G:** *Dry developer application in a vortex chamber*
- H:** *Developing line*
- I:** *Visual evaluation under UV light*
- J:** *Used wash water recycling (doubled active carbon filtering column)*

**Fig. 3.** Fully automated testing system for forgings, plan view



**Fig. 4.** Fully automated testing system for forgings  
(due to a non-disclosure agreement the original components cannot be shown)



At the loading station the components are manually placed on workpiece holders that are optimized for the components geometry. Once the workpiece holder is inserted manually the system takes over control of the transport for the entire testing line. Penetrant application is done by pneumatic lowering of the workpiece holder into a dip tank. After a drainage station, in which the penetrant dwell time is completed, the workpiece holder is passed through a tunnel with many water jets, where the penetrant is removed with predefined water pressure, see fig. 5.

The used wash water is environmental-friendly cleaned in an active carbon filtering column, so it can be used again for penetrant removal. Two identical, but independently working filtering columns are supplied to ensure a continuous testing operation.



**Fig. 5.** Workpiece holder just before passing into the water jet tunnel for penetrant removal



**Fig. 6.** Dry developer application in a vortex chamber

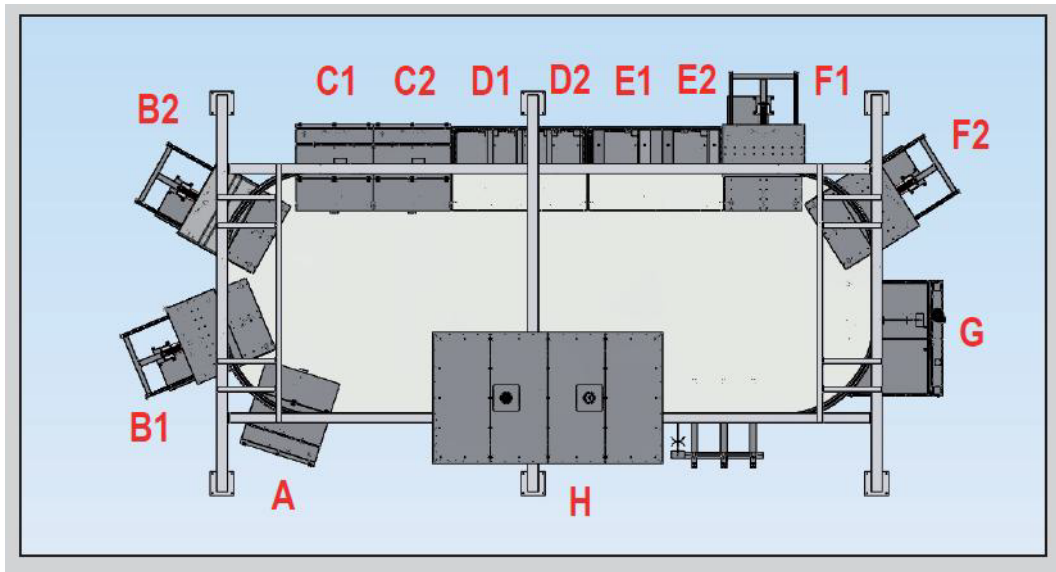
After passing a buffer station the components are dried with warm, circulated air. The dry developer is applied in a vortex chamber (fig. 6). A funnel at the bottom of the vortex chamber is filled with the dry developer. The developer is circulated by means of air with controlled pressure and the components get evenly dusted. The vortex chamber is entirely closed during operation so the dry developer is kept inside of the station. Finally, the workpieces are moved into the evaluation station and are visually inspected under UV light.

#### **4. Semi-Automated Testing of Forgings and Transport via a Crane Runway**

The third presented system, see fig. 7 and fig. 8, provides an extra high throughput of 4500 components per day. Therefore, nearly all stations of the system are doubly installed. The testing objects are forged aluminum components for the automotive industry.

After pre-cleaning the components are placed in a workpiece holder with a capacity of up to 24 parts. The components stay in this workpiece holder during the whole testing process until they are passed into the evaluation station. The workpiece holders are hanging on crabs and are driven along the oval crane runway. In total, nine crabs are mounted to the crane runway which connects all stations of the testing system.

To start the respective process steps the workpiece holders are inserted into the specific station. All stations are equipped with guiding aids for perfect workpiece positions within the tanks. Via proximity switches the system recognizes that the station is loaded and starts the respective process step. The supervision of the system does not control the correct sequence of the process steps and therefore this is the operator's task.



**Stations of the Testing System**

- A: *Pre-cleaning*
- B: *Dryer*
- C: *Penetrant application*
- D: *Penetrant drainage*
- E: *Penetrant removal*
- F: *Dryer*
- G: *Electrostatic application of dry developer*
- H: *Visual examination under UV light in the darkroom*

**Fig. 7.** Semi-automated testing system with oval crane runway (top view)



**Fig. 8.** Semi-automated testing system with oval crane runway

After pre-cleaning with subsequent drying the components are dipped into the penetrant tank, see fig. 9. After a dipping time of 2 minutes, the excess penetrant is drained for further 9 minutes in the next station. So a total penetrant dwell time of 11 minutes is realized. The penetrant tanks are monitored regarding penetrant temperature and fluid level.



**Fig. 9.** Placement of the workpiece holder into the penetrant tank (due to a non-disclosure agreement the original components cannot be shown)



**Fig. 10.** Penetrant removal with water jets



**Fig. 11.** Doubly installed active carbon filter columns for used wash water recycling



**Fig. 12.** Electrostatic dry developer application



**Fig. 13.** Cabin for visual evaluation. The workpiece holder with a capacity of up to 24 parts is hanging at one of the nine crabs.



**Fig. 14.** Signal lamps show the status of each station (green: station waiting, yellow: station working, yellow blinking: station ready)

Penetrant removal with water is done in the automatic washing station, see fig. 10. Water amount and pressure are controlled automatically via the electric control system (PLC). In the doubly installed filter columns, see fig. 11, the used wash water is regenerated to such a degree, that it can be reused again for penetrant removal. Subsequently the components are passed into the drying oven. A thermocouple element measures and the PLC regulates the correct and maximum allowed temperature. Dry developer application is done in the developing station with the aid of an electrostatic spraying gun, see fig. 12. Developing time is 11 minutes, the same as the penetrant dwell time.

After dry developer application the workpiece holder is moved into the evaluation cabin, see fig. 13. Here the components are examined under UV light and defective parts are separated. All stations are provided with signal lamps indicating the current status, see fig. 14.