An Innovation in Horizontal Processing. (Part 1)

Peter Lymn
Ken Bishop
Cemco-FSL Ltd

PCB fabricators have used horizontal roller conveyers to transport copper clad laminate through chemical spray Treatment chambers for many years. These simple conveyorised spray processors have evolved over time to accommodate much thinner materials but the complication of guiding and supporting them through spray jets generally means two types of machine are required; one for thick rigid material and another longer, more complex system for very thin or flexible substrates. More recently this type of equipment has been further adapted to incorporate immersion chambers for plating and other surface treatment processes where spray jets are not suitable. The need to contain the static head above the roller transport system and the relatively long contact times required for immersion processes make these systems even longer and more complex.

This paper describes a non-contact laminar or streamline flow process chamber that results in a faster and more uniform chemical reaction than obtainable with conventional flood chambers. It also describes a transport and guiding method suitable for both thick and thin materials and expands on the mechanics and fluid dynamics that further reduce equipment length and operating cost.

Chemical Process Chamber

In conventional immersion chambers, fluid is pumped from a sump to a dammed roller conveyor chamber. The solution is re-circulated at a rate of typically five times the chamber volume per minute through manifolds positioned between conveyor rollers. Transportation is achieved by using roller wheels to avoid excessive masking of the panel being processed. This combination of flooded jet and roller wheel transport results in chaotic turbulent zones within a relatively stagnant bath and variable chemical reaction across the panel.

The Fluid Engine immersion chambers by contrast, provide laminar flow up to 100X the chamber volume per minute or in excess of 11 meter per minute resulting in faster, more uniform reactions.

The engine comprises two plates closed at each side to form a narrow chamber. Fluid containment rollers, mounted at the entry and exit of the chamber, push and pull both flexible and rigid materials through it. Fluid is injected at the centre of each plate producing a laminar flow towards the entry and exit ends of the chamber.

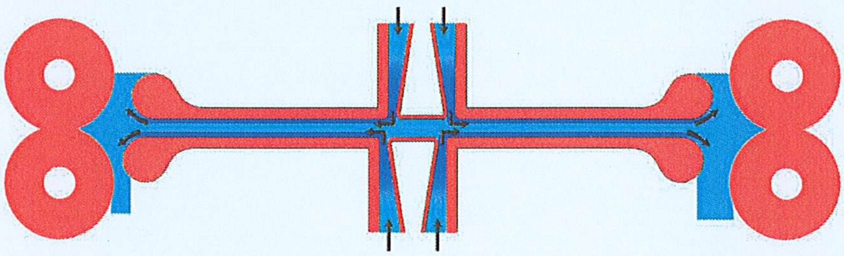


Figure 1: Diagrammatic view of the Fluid Engine showing the laminar flow and the Coanda effect.

This laminar flow results in steady boundary layers above and below the material being processed helping to guide it through the process chamber. The leading and trailing edges of the plates are shaped to produce a Coanda effect, diverting the boundary layer diffusion point away from the panel entry and exit zones. This maintains the streamline flow and diverts fluid above the plates, preventing flooding and material deflection.

Dual Feed Engine

Some chemical processes associated with the printed circuit industry require a gas (normally oxygen in the form of air) to be introduced at the point of contact of the chemical with the panel being processed. A dual fluid version of the Streamline Fluid Engine that simultaneously feeds gas and liquid to the discharge slots provides this facility whilst maintaining the characteristics associated with the standard Fluid Engine.

The design of this engine is illustrated in figure 2.

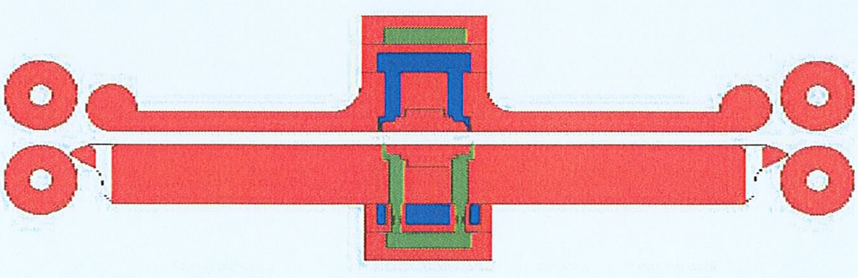


Figure 2 Dual Fluid Engine to introduce a gas into the chemical stream

The gas is fed under pressure to the outer gas plenum (shown in green) that is separated from the liquid plenum by a permeable membrane. The base plate has a series of closely spaced holes that normally connect the base plate directly to the liquid plenum across the width. In the dual feed head the liquid plenum has a series of tubes that connect the gas plenum to the baseplate. These tubes are pitched such that they line up with every other hole in the base plate and seal the holes from the liquid in the plenum. Therefore gas and liquid are delivered side by side across the width of the panel through alternate holes. Figure 2 illustrates how both gas and chemical reach the output jets. The lower head shows the path that the gas takes to reach the jets and the upper head shows how the chemical does. Gas is shown as green and chemical as blue.

Fluid Knife

Where it is necessary to remove chemicals from the panel by dilution, or high fluid impingement is required to wet blind features, a shorter version of the Fluid Engine, known as a Fluid Knife, is used.

Typically this Fluid Knife is used for water rinsing after a chemical process or pre treating prior to a chemical process

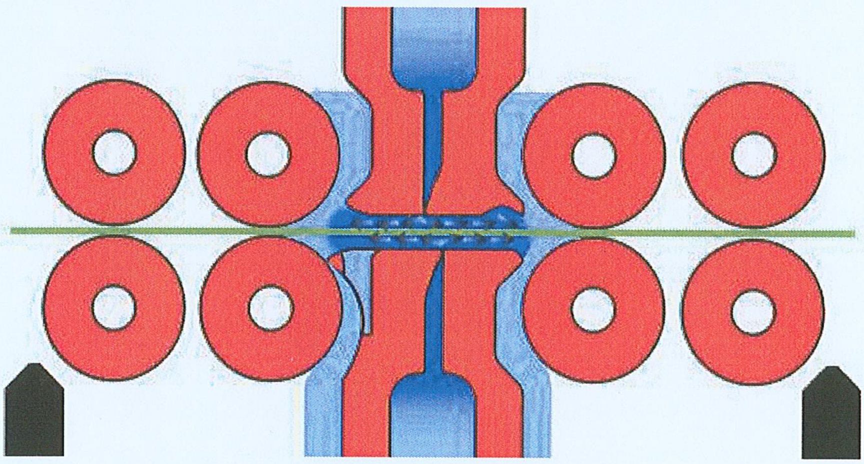


Figure 3 Fluid Knife showing passage of panel through knife and flow of fluid

The Fluid Knife considerably reduces both the conveyor length and the power required to pump solution onto the panel. For example a single Fluid Knife provides a solution rate of 40 litres per minute using a 110-watt pump compared to a more conventional spray rinse that delivers 28 litres per minute from a 750-watt pump. Similarly the Fluid Knife requires only 170mm of conveyor length compared to 240mm for the spray rinse.

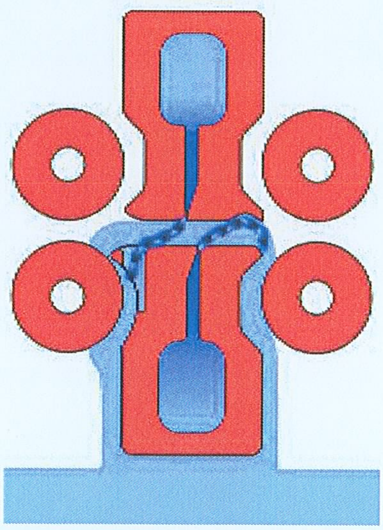


Figure 4: Fluid Knife showing fluid flowing to the side of a panel passing through the knife.

As with the Fluid Engine thin material transport is assisted by the fluid flow characteristics although the proportionally lower flow rate negates the need for the overhead fluid deflection, the upper outflow being deflected to the sides.

The liquid that escapes to each side of the panels is deflected downward using Coanda effect guides on the bottom knife and a jet deflector on the exit of the upper knife. This negates the need for segmented containment rollers or extended entry and exit zones. (see figure 4).

Jet Knifes.

The Jet Knife provides multiple upper and lower high impingement conventional spray jets to displace salts, fluxes and other 'contaminants' that are not readily dissolved.

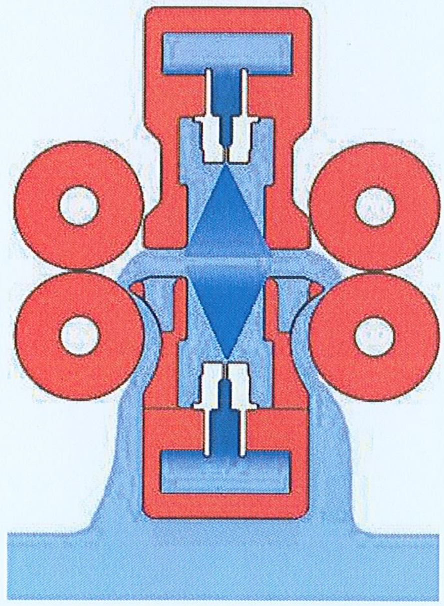


Figure 5: Jet Knife

The offset opposing jets balance material between the rollers and the ported entry and exit guides, ensure contactless entry and exit to the spray zone. Drainage holes in the lower chamber ensure that fluid is dispersed quickly and does not flood over the isolation rollers. The space required is the same as for a Fluid Knife but requires a higher power pump.

Drying with a Fluid Knife.

Based on the knives originally developed and patented for Hot Air Levelling these single slot knives are shaped so that a pressure differential is produced between the upper and lower surfaces of the panel. Each knife has a series of slots cut in the leading edge separated by narrow panel guides. The cutout in the lower knife is shaped so that air leaving the lower jet expands rapidly producing a low-pressure area below the panel.

This low-pressure draws water from the holes before the panel reaches the air jet and directs it to the bottom of the drying chamber. The force created by the pressure difference either side of the panel also stabilises the panel's position in relation to the lower knife and its integral guiding system.

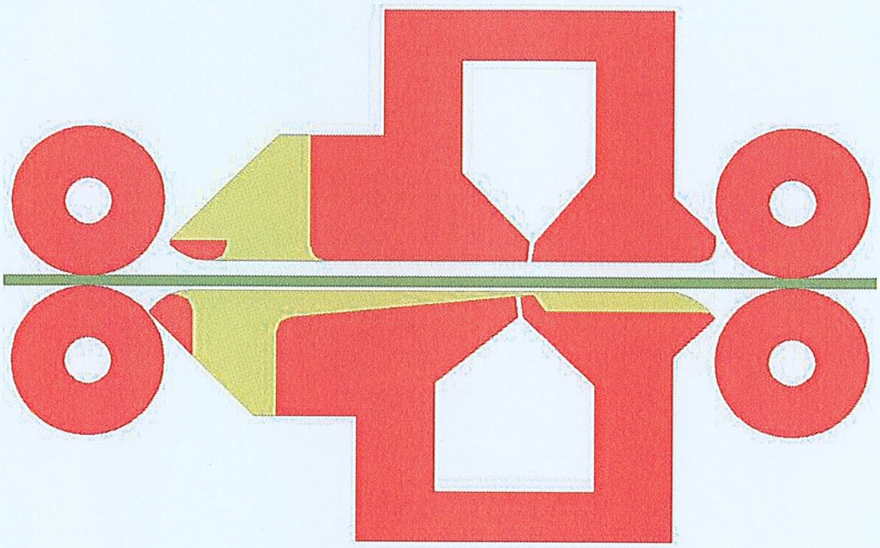


Figure 6 Drying Knife

When drying thicker material, problems can be encountered where water is left on the trailing edge of the panel. Although the water is removed from the surface by the jets a small amount remains along the trailing vertical face of the panel and returns to the horizontal face once the panel is clear of the jets. The thicker the panel the more water is likely to remain there.

A Fluid Knife incorporating the inclined knife technique, described in our earlier dryer patent, can successfully removed water from the trailing edge. In this design the air jet is inclined across the width of the conveyor. Water is removed from the surface and driven across the panel and effectively "wiped" off the trailing face by the jets.

Each parallel jet knife set occupies the space of just two roller pitches. Due to the angle of the slot used in the inclined jet knife producing a wider unit this design occupies 4 conveyor slots. Additional space is needed to preventpressurisation of preceding chambers by the air from the jets, this spacebeing filled with conveyor rollers.

Using the Fluid Knife technique, thicker panels can be dried and fitting both parallel and inclined knifes in sequence provides higher speed capability.

Coanda effect.

Discovered by **Henri-Marie Coanda**, a Romanian born aeronautical engineer and named after him, the coanda or wall attachment effect is the tendency for a moving fluid to attach itself to a surface and flow along it.

When a fluid moves across a surface a frictional force occurs between the fluid and the surface and slows it down. This resistance to the flow pulls the fluid towards the surface, causing the fluid to stick to the surface Therefore, a fluid flowing from a nozzle will follow a nearby curved surface if the curvature of the surface is not too sharp.

Coanda first noticed this effect when during a short flight of an experimental aircraft he observed that the burning exhaust gases from the engine seemed to hug the sides of the aircraft very closely and the plane caught fire and crashed.

Luckily he survived.

A simple illustration of the coanda effect can be demonstrated by placing the back of a spoon against a stream of water flowing from a tap. The stream will be deflected to follow the shape of the spoon as it hugs the surface.

Combining the processes

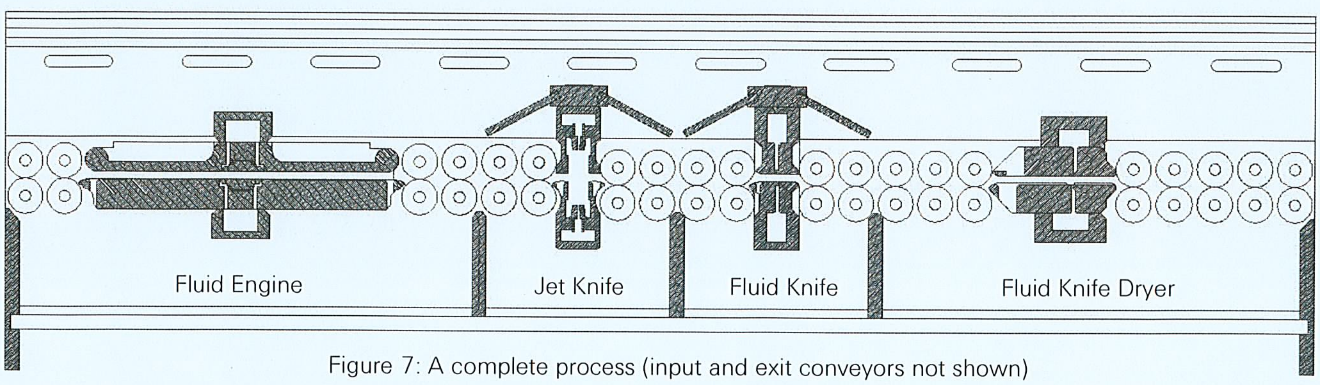


Figure 7: A complete process (input and exit conveyors not shown)

Figure 7 illustrates a simple horizontal treatment line using the Fluid Engine technology.

The first stage is a chemical process using the Fluid Engine.

Following this is a cleaning section consisting of a Jet Knife providing high fluid impingement forces and a Fluid Knife as the final rinse stage.

The last section dries the panel before exiting onto the output conveyor.

Each wet process section is separated from the next by fluid isolation bulkheads that allow the solution flowing from the head to flow back to the appropriate sump for recirculation.

Ken Bishop

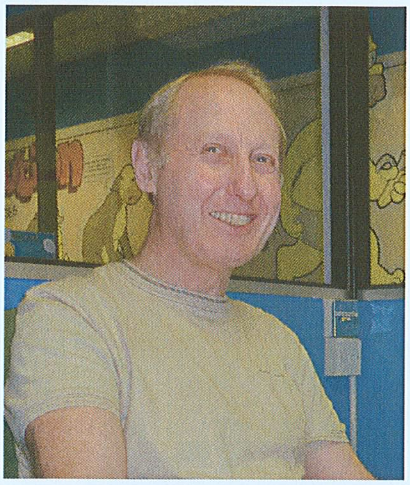
Peter Lymn

Cemco-FSL Ltd

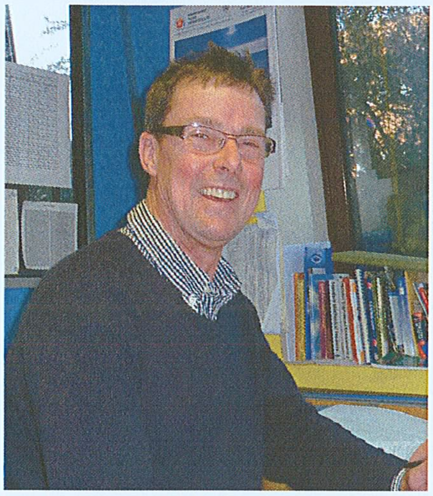
http://www.cemco.com

(the concluding Part 2 will appear in January 2010)

An Innovation in Horizontal Processing. (Part 2)



Ken Bishop C Eng MIET
Technical Director - Cemco-FSL



Len Flint
Senior Development Eng. - Cemco-FSL

The first paper on this subject covered the theory behind a novel non-contact laminar or streamline flow process chamber that results in a faster and more uniform chemical reaction than obtainable with conventional flood chambers. It also described a number of variations on this chamber to provide a solution to a complete horizontal chemical processing line that reduced the footprint and operating cost over conventional designs.
This second paper describes a practical implementation of the design. It further describes how the design has been developed to produce equipment capable of processing material in a variety of chemical applications.

Note: Many of the figures in this paper are from a 3D CAD design software package. They are coloured for clarity and do not represent the colours used in practice.

Fluid Engine

A basic Fluid Engine is made up of an upper and lower fluid head screwed together to make a complete, easily removed assembly (figure 1).

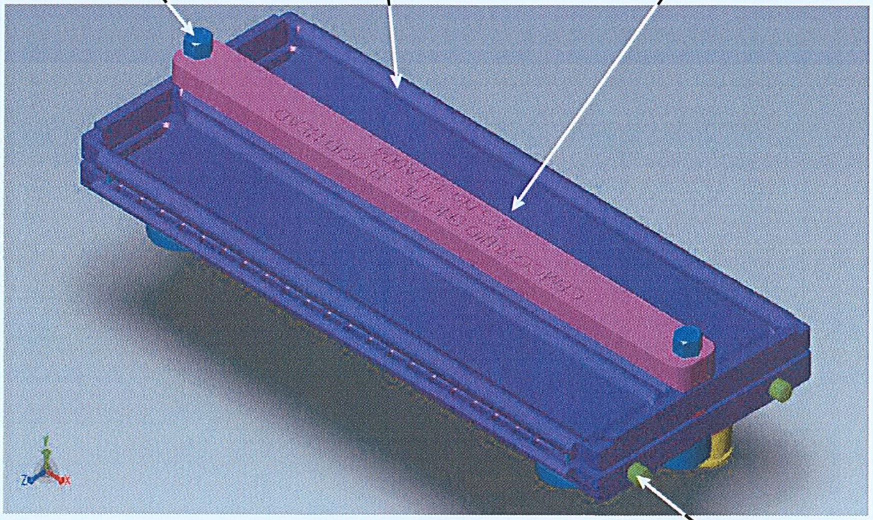


Fig 1. Fluid Engine assembly

Each head comprises a base plate machined from a solid piece of plastic and a plastic plenum welded to it. Both base plates have drainage slots to allow any fluid that accumulates on the top head to drain back into the chamber and then to the sump. The complete Fluid Engine assembly slots into the side frames of the conveyor using two location spigots fitted on a multiple of the conveyor pitch either side of the lower head.

A plastic strip screwed into the base plate creates the two fluid discharge slots. This strip can be easily removed for cleaning the heads. Strips fitted to either side of the base plate guide the fluid and stop it flowing over the sides of the head. This ensures laminar flow is constant over the whole width of the head. Fluid is fed into the lower head via a pipe connected to the lower plenum whereas the upper head is fed from pipes that pass through the lower head. The fluid feed is fitted with an "O" ring and is a push fit into the feed pipe from the process pump. This enables the Fluid Head to be easily removed and refitted manually.
Figure 2 illustrates these design features.

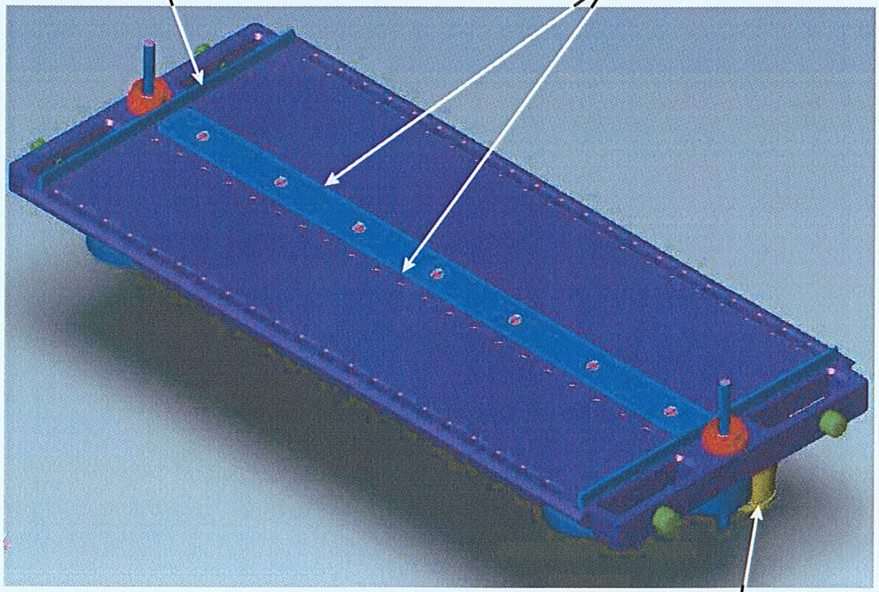


Fig 2. Lower Fluid Head

When a heated chemical is used with the Fluid Engine, the upper head is fitted with a pair of condenser plates (Figure 3). The hot chemical vapour condenses on the under side of these plates and runs back into the chamber. The plates are cooled to encourage condensation by drawing ambient air across the top utilising the fume extraction system. The assembly simply slots together and drops over the two nuts that hold the upper & lower heads together. There are no fixings and therefore the plates can be easily lifted off the fluid engine for cleaning.

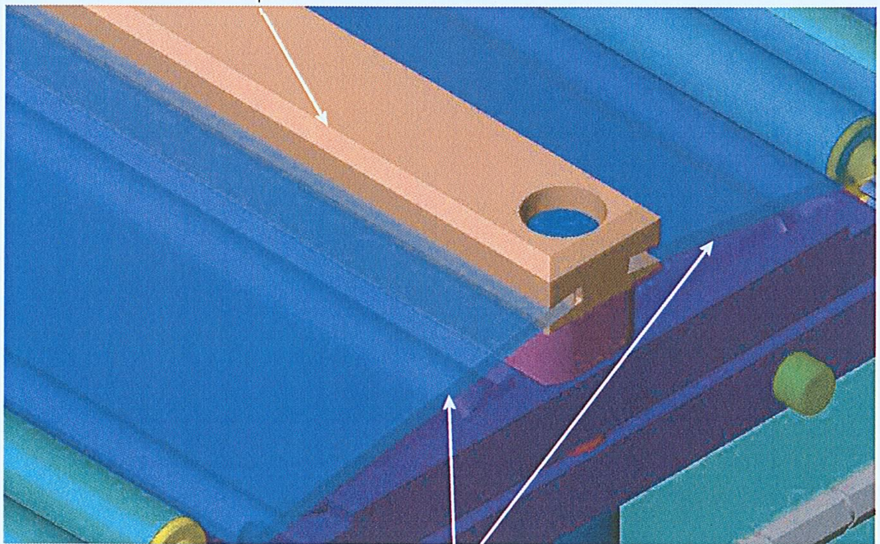


Fig. 3 Vapour condenser plates

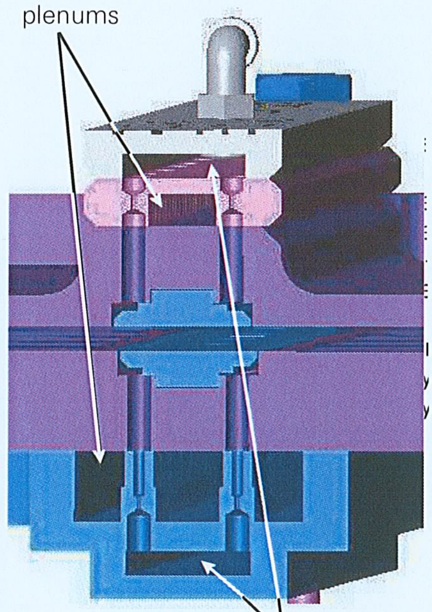


Fig.5 Fluid paths for Dual Fluid Engine

Dual Feed Engine

The dual feed Fluid Engine is very similar in construction to the basic engine. The difference is in the way that the second fluid is delivered to the base plate and on to the discharge slots.

The base plate is exactly the same design but the liquid plenum is changed to enable the gas to pass through it and into the base plate. The plenum is machined so that a series of tubes pass directly through it. These tubes provide a path for the gas though the liquid plenum. The gas plenum is a hollowed out plastic block with a tapped hole for the gas feed fitting. The two plenums are welded together to give a fluid tight construction and then welded to the base plate. The liquid plenum is positioned such that the tubes align with every other hole in the base plate. The result is that gas and liquid exit the discharge slots from alternate holes spaced at approximately 7mm across the width of the panel being processed. By adjusting the pressure of the gas at the input port the mix of gas and liquid arriving at the panel can be controlled.

Figure 5 shows a cross section through a Dual Fluid Engine and shows the paths that the two fluids take to reach the discharge slots. The top head shows the liquid path while the lower head shows the gas path. A membrane is fitted between the two plenums that allows gas to pass through to the discharge slots but prevents liquid from flowing back to the gas plenum. The lower liquid plenum is larger than the upper as the liquid fed to both upper and lower discharge slots has to pass through the lower one.

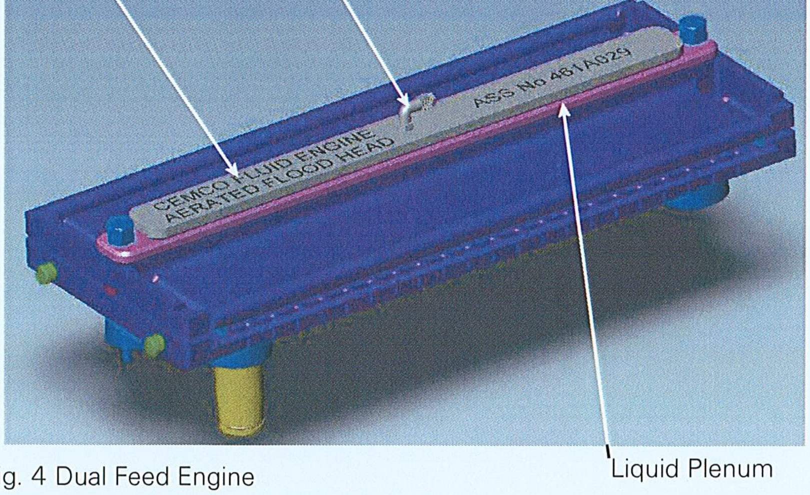


Fig. 4 Dual Feed Engine

Fluid Knife

The fluid knife does not have to provide a long contact time between the fluid and the material and so is considerably narrower than the Fluid Engine. Both upper and lower heads consist of two plastic plates hollowed out to provide a plenum area. These plates are welded together to produce the complete head assembly. The weld line can be seen in figure 6 running across the length of the heads. The plates are machined to produce a fluid discharge slot running across the width. The plates are further fixed together using plastic screws to overcome the tendency of the plastic to bow over its length. This ensures that the discharge slot width remains constant producing an even flow of fluid. The leading edge of the lower knife has a series of slots machined in it shaped to allow the fluid to rapidly drain into the chamber. This allows the knife to be positioned extremely close to the input roller with the leading edge acting as a guide for thin material. A single location spigot is fitted either side of the lower head to position the knife assembly in the conveyor side frame.

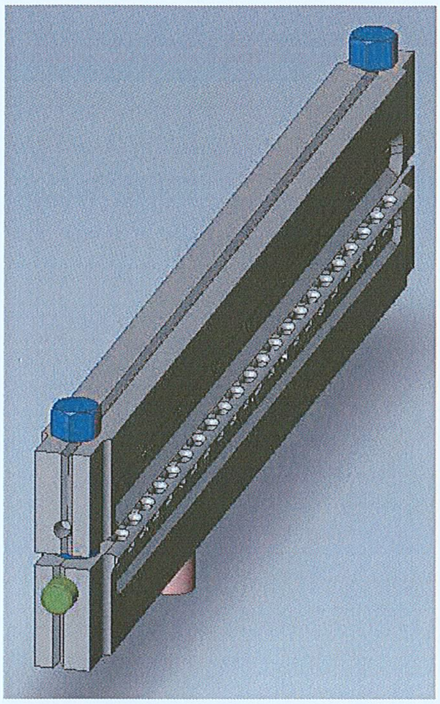


Fig. 6 Fluid knife assembly

Jet Knife

Based on similar design concept as the fluid knife with two machined plastic plates welded together the Jet Knife has a series of holes tapped in the plenum. These tapped holes can accept standard moulded jets to provide high impingement forces on the panel.

Drain holes in the base of the lower head allow fluid to drain away rapidly to prevent it interfering with the spray pattern from the lower jets.

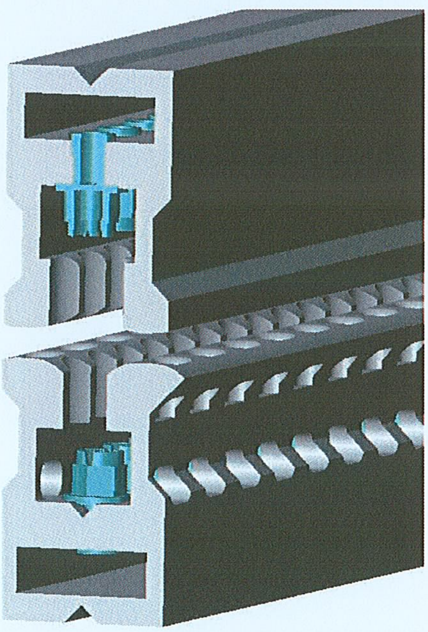


Fig. 7 Cross section through a Jet Knife

Spray applications.

Although it has been found that most of the chemicals traditionally sprayed can be used to advantage in the fluid engine it has been anticipated that spray treatment may be required. To meet this requirement a module that can be fitted with either fluid engine or spray manifold has been developed.

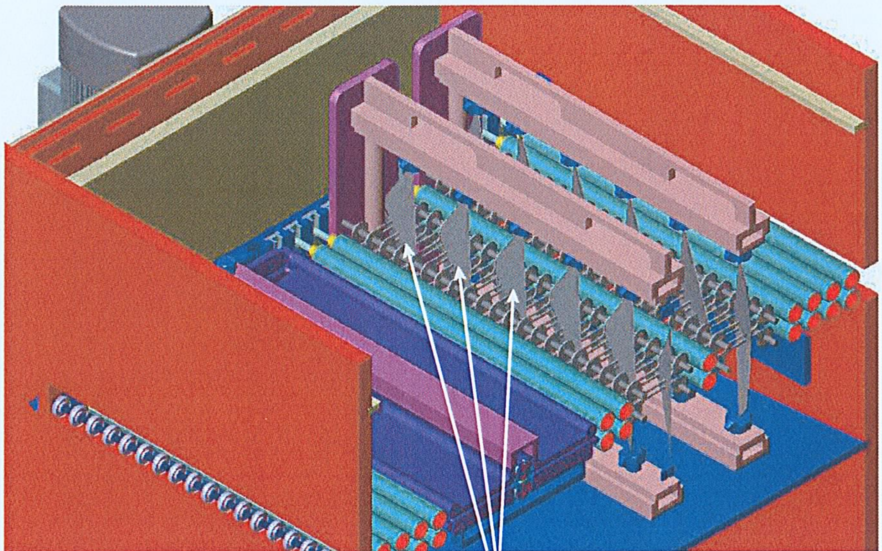


Fig.8 Spray applications

Figure 8 shows a typical process section combining Fluid Engine and Spray Modules. Both top entry Fluid Engine and Spray Module are 'plugged in' to their supply manifold and are located in the conveyor side frames. Two single spray bar manifold assemblies fit the area occupied by one fluid engine and are interchangeable to facilitate testing and development. The design of the Spray Modules enables standard jets to be fitted providing the facility to generate a variety of spray patterns. Jets are spaced above and below the work to produce the desired fluid coverage. The jets shown in the figure are angled to provide coverage without interfering with fluid flow from adjacent jets.

Drying Knife

Material drying is achieved using a variation on the fluid knife design. Delivery of air to the discharge slots is the same as liquid delivery in the fluid knife. The path that the air takes however is different than that taken by liquids. Both top and bottom drying knives have extended input sections to help guide the panel into the air stream.

The lower knife is shaped to rapidly expand the air leaving the jet to produce a pressure difference between the top and bottom of the panel. This pressure difference sucks fluid from the holes in the panel and also helps to stabilise its position between the knives.

To avoid the problem of water left on the trailing edge of panels the knife jets are angled across the width of the conveyor. This causes the air to produce a "wiping" action across the panel driving excess water to the corner where it falls into the lower chamber and to drain.

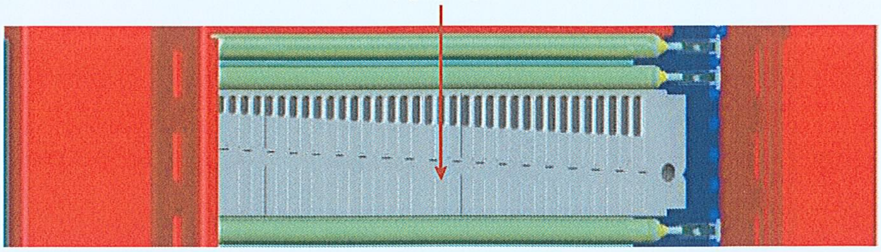


Figure 9 shows the lower air knife and illustrates its angular jet design.

Material transport

The conveyor system is housed in a series of wrap around plastic shells the number of shells being dictated by the length of the process. Running along the length of each shell are two side frames with slots cut at the conveyor pitch.

A slide in roller bearing block is fitted to every slot where a conveyor roller is located. The lower rollers are fitted with a bevel gear that picks up the drive from another bevel gear fitted to the common shaft that runs the length of the module. Each bevel gear set drives 2 upper and 2 lower rollers. A train of spur gears drive the slave roller and upper and lower spur gears provide positive drive to all rollers. Figure 10 shows how the drive is transferred from the main drive shaft to the rollers via the module drive shaft and the bevel gears.

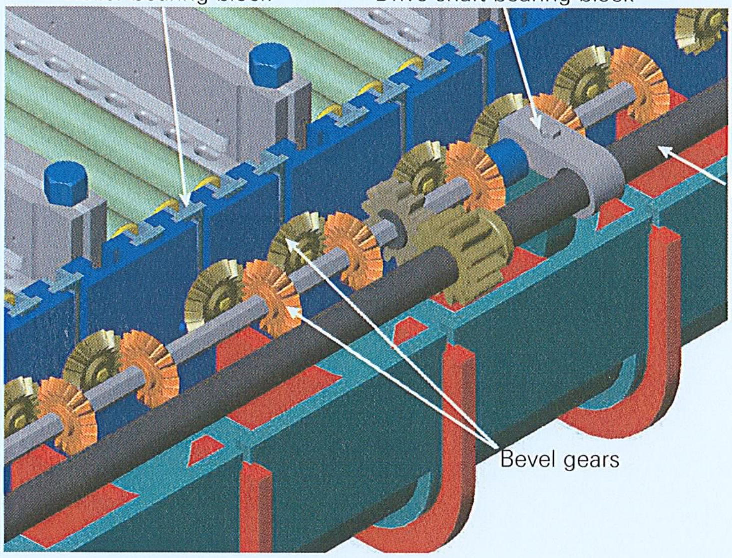


Fig. 10 Roller Drive System - Note: Upper rollers are removed for clarity.

One of the design objectives for the conveyor system was to provide the capability of transporting a variety of material with thickness from 0.005 to 5.0mm. The roller diameter has been selected such that the flex strength of 50-micron kapton is sufficient to overcome the capillary attraction of a wet roller and the gap between rollers is sufficient to prevent capillary attraction between them to reduce carry over. The spur gears that transfer the drive from the bottom to top rollers have a special tooth design to achieve positive drive with panels up to 5mm thick.

Figure 11 illustrates how the rollers are coupled via the spur gears on the drive side.The second top roller is driven from the other end of the lower roller immediately below it with spur gears mounted on the opposite end of the rollers.The rollers are fabricated from light, rigid hollow carbon fibre cores, to prevent deflection or damage when dropped, and alternative precision ground coatings are available to suit all chemicals. Drag out can be improved by increasing the weight of the upper rollers by inserting weights into the inner core.

Bearing blocks fixed directly to the side frames at either end of the module support the module drive shaft. Each module drive shaft picks up its drive from a spur gear on the main drive shaft. The separate drive shaft design enables a long drive train to be assembled without the possibility of potential drive shaft wind up. For longer lines or where composite lines running at multiple speeds are required the drive shaft can be split into two or more sections with a separate motor for each section of shaft. In these cases the motors can either be run from a common speed control where synchronous speeds are required or separate ones where different section speeds are needed.

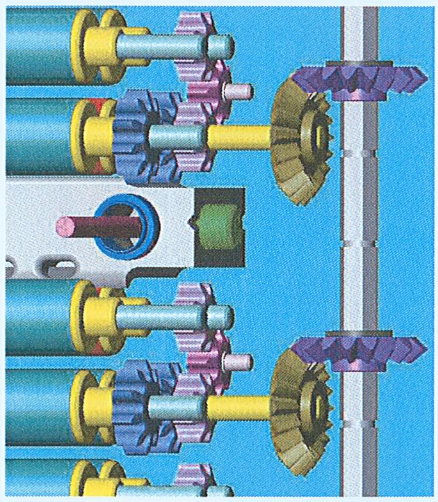


Fig.11 Transer of drive from driven rollers to other rollers.

Practical applications

Equipment using the Streamline techniques currently in use in, or being developed for, the PCB industry include surface conversion processes such as electroless silver and tin and surface treatment processes that conventionally demand spray application or significantly longer contact time. A low flow variant of the fluid engine has been developed for nano-coatings and is currently entering the third phase of evaluation. This and the application and capability of the fluid engine as an alternative to complex spray application for etching and similar processes will form the subjects of a further article.

By working with specialist manufactures and chemical suppliers Cemco has successfully implemented many aspects of the Streamline designs discussed in these two articles into equipment for use outside the PCB industry. These include electroless and electrolytic copper plating and surface treatments for RFID and Photo Voltaic and are currently being designed into aluminium web anodising equipment.

Many of the design concepts illustrated in this article have been protected under the following patents.

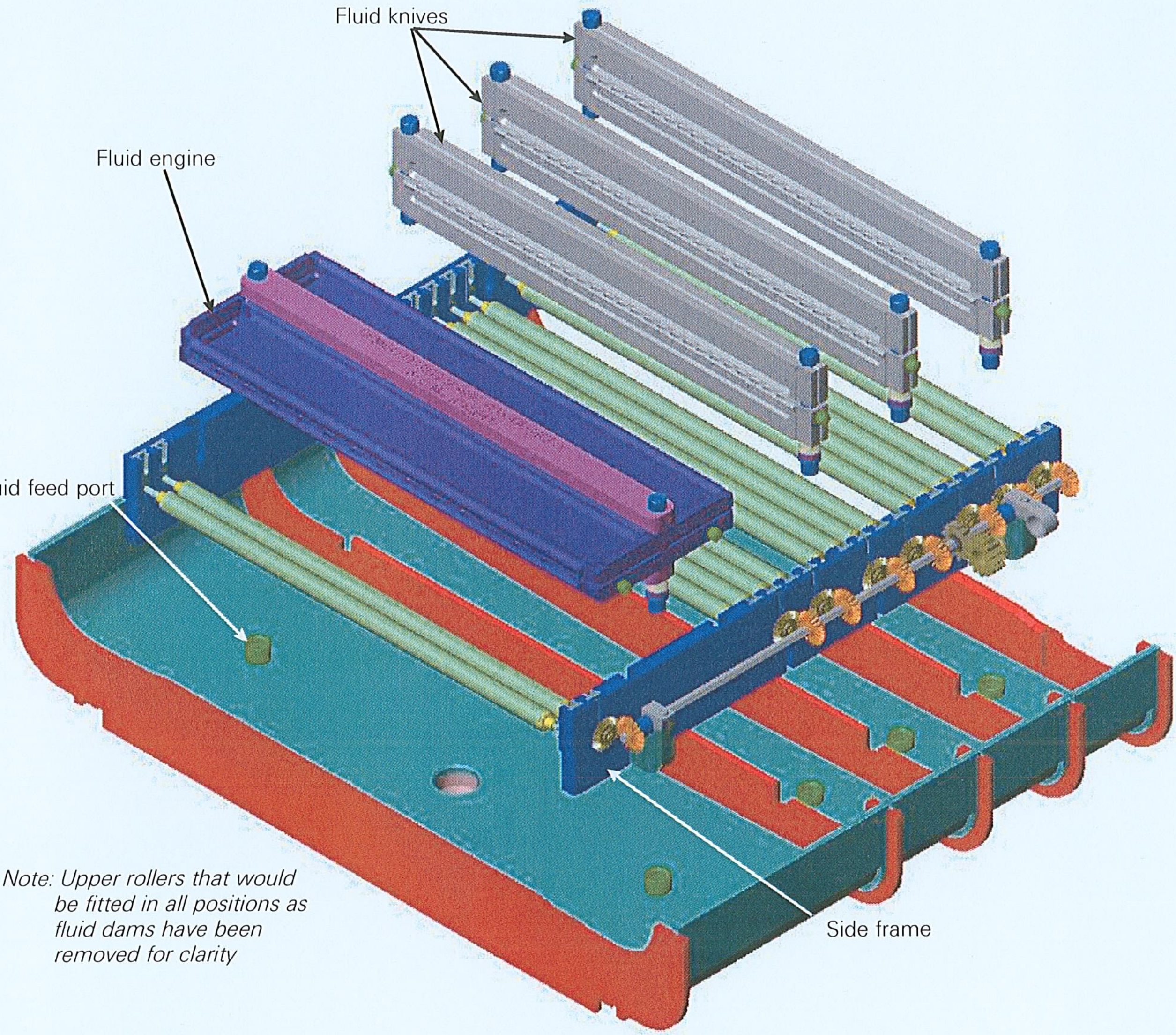
Pat No's. UK.2351458: GR.100 25 619 8: USA.6440215. USA.5155926
GB. 0827800: GR. 697 13 693.0-08; USA 5876499
Pat App No: PCT/GB2008/000062; WO2009/044124 A2.

Combining the processes

Figure 12 is an exploded view showing how a section of the Streamline process is built up and illustrates its modular construction and ease of maintenance.

This particular module shows a single Fluid Head chemical process followed by a triple water rinse section fitted with Fluid Knives.

The engines and knifes plug into feed ports built into the base of the conveyor chamber, one feeding the upper plenum and the other the lower plenum. The engines can be fed from horizontal or vertical pumps in either remote or integral sumps the former allowing wall mounting to further save space.



Note: Upper rollers that would be fitted in all positions as fluid dams have been removed for clarity

A typical complete line consists of multiple modules similar to figure 12 with combinations of Fluid Heads and Fluid Knives tailored to the complete process. The individual modules would be coupled together and driven from a single drive module.

A slave conveyor section is usually fitted to the output end of the line to allow processed panels to be removed. A panel feeder is available for fitting to the input conveyor section while a panel stacker can be included on the output conveyor.

Peter Lymn
Ken Bishop
Len Flint
Circuit Engineering Marketing Co.Ltd. (CEMCO)
December 2009 http://www.cemco.com