Your piezo partner

MANUFACTURING
– tutorial

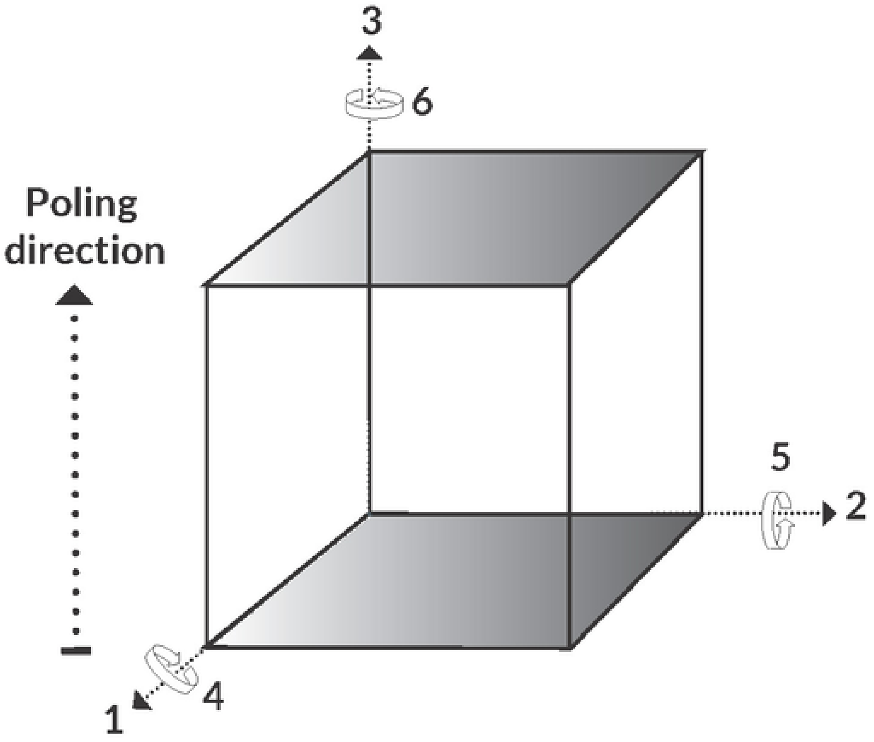
This tutorial gives a basic introduction to the manufacturing process of both monolayer and multilayer piezo products. You will find a short description of the different elements of the manufacturing process in the process flow in the section Manufacturing.

Index of the tutorial on manufacturing:

MONOLAYER

Piezoelectric products can be divided into the following segments: monolayer products with a single layer of piezoelectric material and multilayer products with multiple layers of piezoelectric materials.

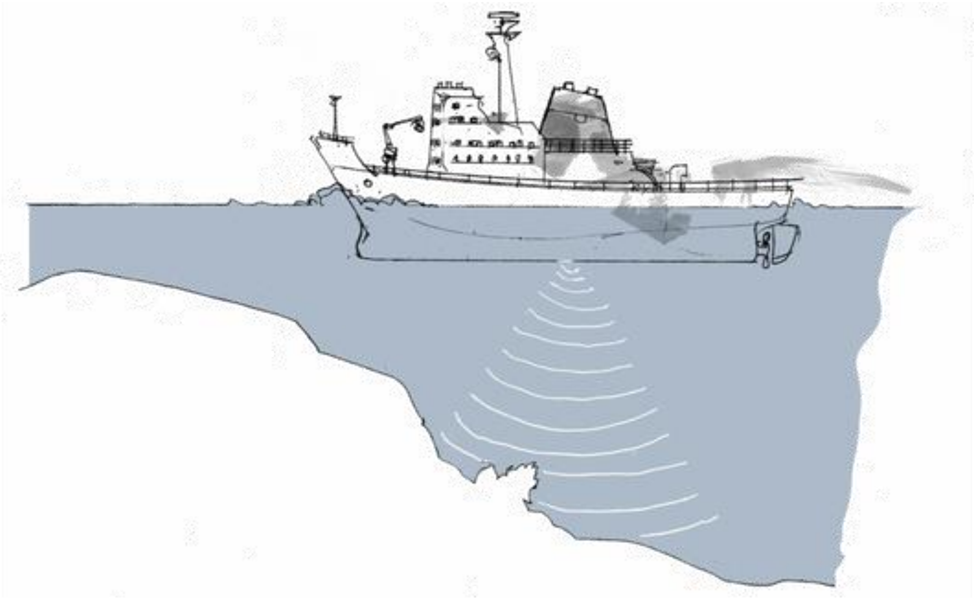
Basics on monolayer



Monolayer piezoceramic material is defined a product with a single layer of piezo with electrically conductive metal electrodes on two opposing sides. These electrodes are used for poling the material (rectifying the electrical dipoles like in magnetic materials) and used for electrical contacts when the component is used in an application. Monolayer piezo components are manufactured by compaction of the piezoceramic powder by conventional processes like uni-axial pressing, isostatic pressing and extrusion.

Common applications for monolayer components

Common applications for monolayer piezo products are large devices for sonar using discs, rings and plates up to several centimetres in diameter, knock sensors for automotive engines using rings approximately 2 centimetres in diameter and sensors for accelerometers using plates and tubes with dimensions less than a centimetre.



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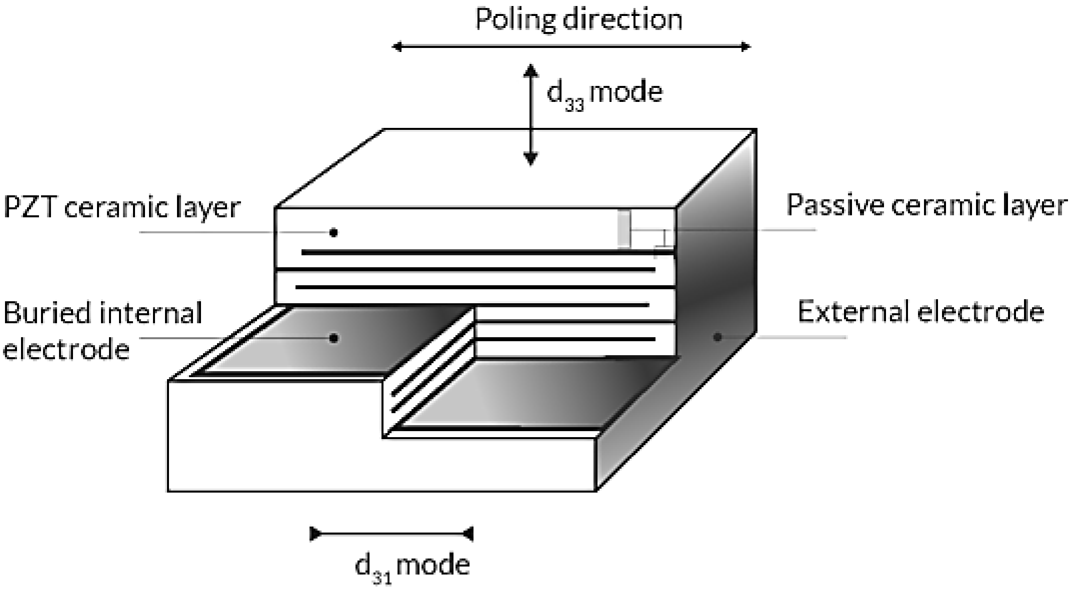
MULTILAYER

While being well adapted for sensor applications the monolayer products are not very well applied for actuator applications. To reach a useful displacement with monolayer you require a very high operating voltage, in the range of 500-1000V. In order to overcome this problem the multilayer technology was developed in the 1980s.

Basics on multilayer



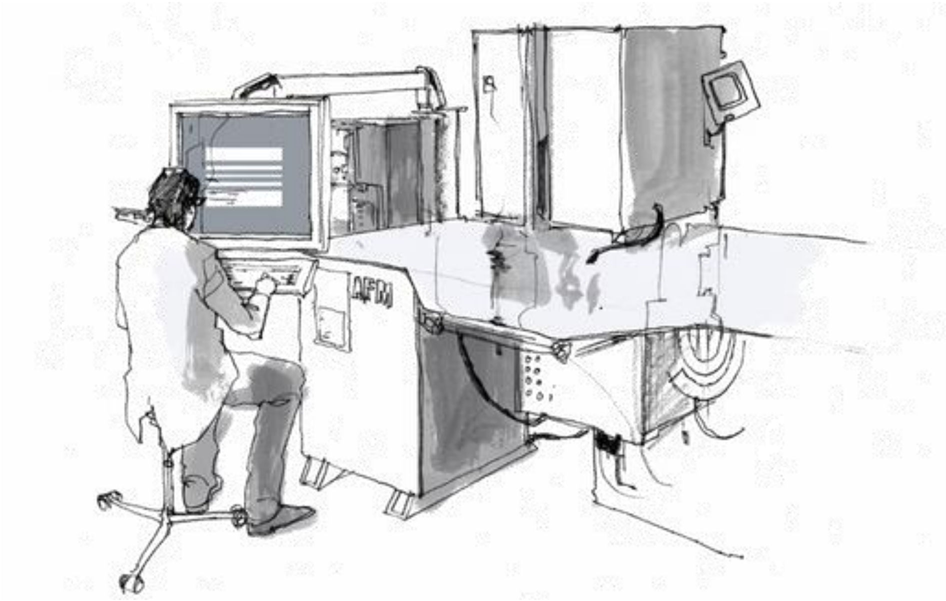
A multilayer component is composed of several layers of piezoelectric material, alternating with internal electrodes. Internal electrodes are successively positive and negative. All positive electrodes are connected by one external electrode on one side of the component; negative electrodes are connected on the other side of the component.

The advantage of this approach is that a factor of 100 lower voltages can be used for the same displacement of actuators. For transformers, the multilayer approach allows for much higher transformation ratios than is possible with transformers based on monolayer piezoceramic material.

The multilayer approach enables designs with multiple functions e.g. integration of sensors in actuators or combination of actuator and generators as with the new transformer concept.

Common applications

Common applications for multilayer piezo products are actuators for micro positioning using stacks in the size range of 5mm x 5mm x 20mm, diesel fuel injection actuators using somewhat larger stacks and optical applications using smaller actuators for fine tuning of mirrors, fibres etc.



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Main differences between monolayer and multilayer

The main differences between these two methods are (for similar dimensions):

- Monolayer components are easier to manufacture
- Multilayer components can be operated under higher electrical field, thus leading to larger static displacement
- Multilayer components can be operated under a lower voltage
- Bulk components have a lower capacitance
- Multilayer components are more resistant to humidity thanks to their embedded electrodes
- Multilayer components can be customised with complex electrode designs and multiple functions in the same component
- Some materials cannot be processed for multilayer components.

MANUFACTURING

The manufacturing process for monolayer and multilayer are both the same and quite different. Monolayer is made of one layer of piezoceramic material pressed with up to 1 MN compacting force. Multilayer is made by tape casting very thin layers of piezoceramic material on which thin layers of electrode material is deposited. Approx. 100 layers are then laminated.

Basic manufacturing of monolayer

The basic technology for the manufacturing of piezoceramic components is the pressing of shaped bodies using spray-dried granular material. This is achieved using high-capacity presses with up to 1 MN compacting force.

The shaped bodies are either manufactured true-to-size, taking into account the sintering contraction, or with machining excesses, which are removed to achieve the required precision.

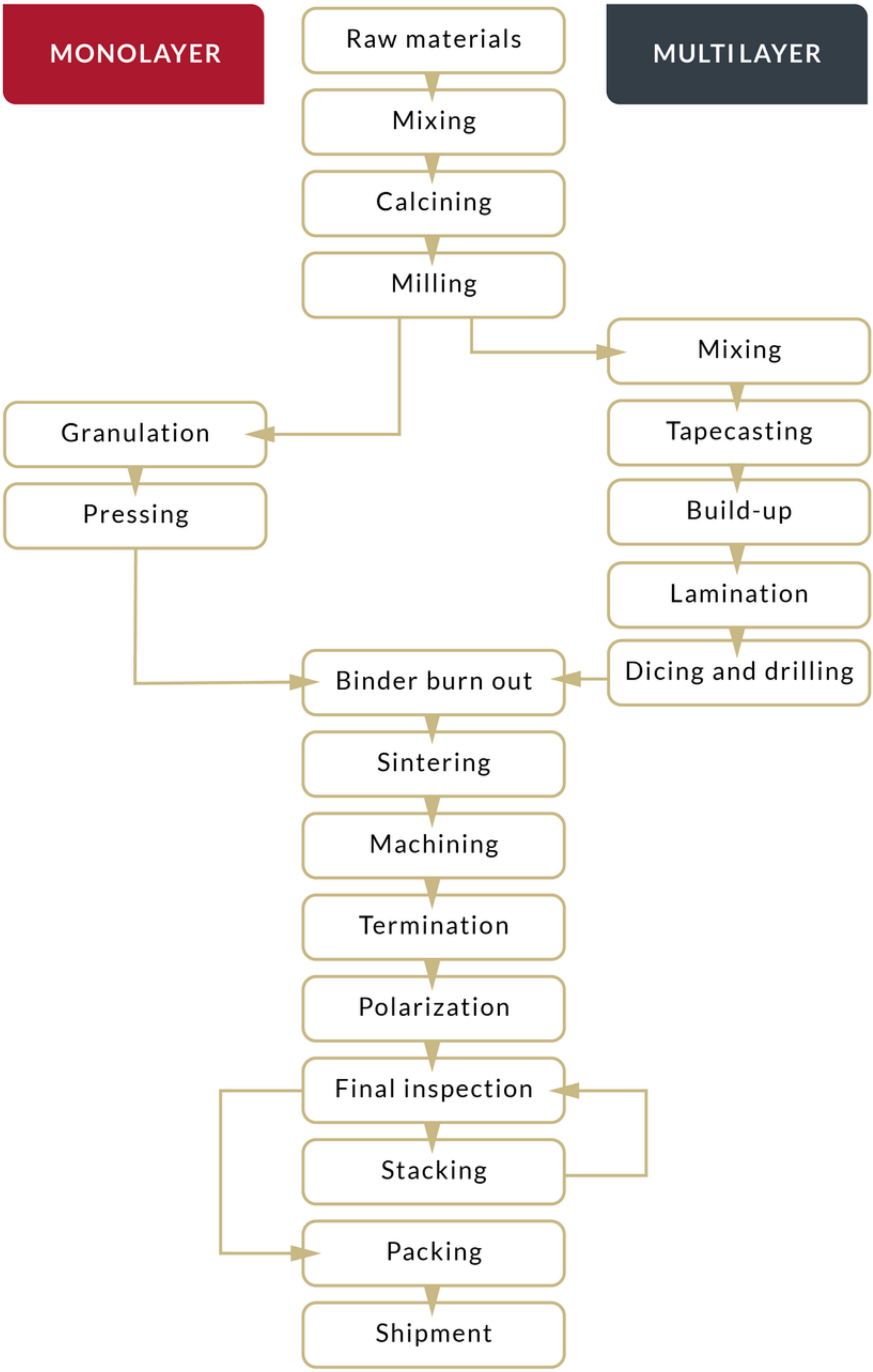
By using high-production inboard diamond sawing equipment, it is possible to manufacture components (discs, plates, tubes, etc.) with a thickness as low as 0.2 mm.

Basic manufacturing of multilayer

Multilayer piezoelectric actuators are produced by tape casting very thin layers of piezoceramic material on which are deposited thin layers of electrode material. Several layers are laminated together to form a monolithic ceramic component with internal electrodes.

Process flow

A flow diagram of the manufacturing processes involved with piezo monolayer and multilayer processing at Noliac is shown below. Each process is described below the diagram.


MONOLAYER
Raw materials
MULTILAYER
Mixing
Calcining
Milling
Mixing
Granulation
Tapecasting
Pressing
Build-up
Lamination
Binder burn out
Dicing and drilling
Sintering
Machining
Termination
Polarization
Final inspection
Stacking
Packing
Shipment

Processes common for both monolayer and multilayer production

Raw materials

Depending on the product about to be produced, the relevant piezoceramic material is taken from stock.

Read more about the different types of piezoelectric materials offered by Noliac

Learn more about piezoelectric materials in the tutorial on materials

Mixing

Piezoceramic powder with a specified particle size is mixed with additives and solvents. All accurately weighed after a well documented prescription.

Calcining

The mixed materials are calcinated at 900-1000 °C to remove organics, water or other volatiles left after mixing.

Milling

The calcinated materials are milled to achieve a very homogeneous suspension. The suspension is measured for viscosity and approved for tape casting or for monolayer production.

Only for monolayer production

Granulation

The powder with binder is now granulated by spray drying.

Pressing

The piezoceramic material is pressed with different pressing tools depending of the shape in production.

Only for multilayer production

Mixing

The powder is mixed with additives and solvents. The mixed materials are milled to form a homogeneous suspension (slurry).

Tape casting

The suspension is tape casted on a carrier foil. The tape thickness is between 20-40 µm as standard. The green ceramic tape contains binder materials, which makes the tape flexible and easy to handle in the following processes.

Build-up

Sheet cutting
The tape roll is cut into sheets and automatically inspected for defects

Printing
Internal electrodes with predetermined patterns are printed on the ceramic sheets with a suitable electrode paste. A final multilayer item will typically consist of 2-5 different electrode patterns. For benders it will be possible to mark the component with e.g. batch number or Customer ID.

Stacking
Layers of ceramic sheets are fully automatically stacked in the right sequence to the final item. All items are build in 6”x6” blocks.

Lamination

The ceramic blocks are laminated at well defined pressure, temperature and time. At this process the layers are firmly laminated and brought in appropriate contact with each other. This process is very critical as either insufficient lamination or too much lamination has significant influence on the quality and accuracy of the products.

Dicing and drilling

After lamination, individual components are diced or drilled out of the green ceramic blocks. Dicing needs to be accurate matched to the pattern of the internal electrodes. Dicing might also be performed on fired ceramic.

Processes common for both monolayer and multilayer production

Binder burn out

The organic compounds in components, binder materials, additives and remaining solvents are removed by very slowly heating the green parts to a temperature, 500-700 °C, where the organic compounds decompose and evaporates from the ceramic.

Sintering

In order for the ceramic grains to grow and merge into a solid polycrystalline structure, the fired parts need to be heated to a temperature above 1000 °C. Several parameters have to be optimized with this process, e.g. temperature ramp rates, holding time and the condition of atmosphere. During sintering the components will shrink approximately 15 %.

Machining

All products are machined or tooled in some manner before or after termination depending on the specific product. The surface roughness depends on the grain size of the abrasive used in the slurry.

Termination

For multilayer products, external electrodes are applied to make a connection to the internal electrodes inside the component. For monolayerproducts, the external layer provides external electrodes for connection and polarization.

After careful cleaning, the components are applied with a conductive electrode paste of typically Ag. The screen printing technique is the preferred applying technique. The electrode paste is fired at a temperature between 600-800 °C depending on the material and will form a conductive layer with a good adhesion to the ceramic surface.

Polarisation

Activation of the piezoelectric ceramic properties is called the “poling” process. In order to obtain the piezoelectric effect in the piezoelectric material, the dipoles in the grains must be aligned. This alignment is achieved in the poling process, where a high electrical field, 2-3kV/mm, is applied to the external electrodes at elevated temperatures (100 - 150 °C) for a period of 1-10 minutes.

Final inspection

After poling the components will go through a final inspection according to customer specifications or internal procedures, which is a combination of statistical method with level AQL 0.65 and 100 % measurements. Various mechanical and electrical parameters might be tested - also according to customer specifications. Mostly capacitance, dielectric loss and mechanical strain level (stroke) are specified for inspection.

Stacking

Single monolayer as well as single multilayer elements can be stacked. The elements are glued together with glue that can be soft, medium hard or hard depending on the application they are used in.

The single stack is typically connected electrically with a bus wire. The stacks are inspected according to level AQL 0.65 and the parameters measured are stroke, height and capacitance.

Packaging

Components will be packed properly in plastic trays, plastic bags, foam or placed on tape and then placed in a grey box with the Noliac logo.

Shipment

We use couriers for shipment of packages and are able to dispatch up to four Noliac boxes in one shipment.

TEST PROCEDURES

Multilayer actuators are tested during manufacturing and in final inspection before shipment. The tests and requirements shown in the table below are performed as standard. Additional tests and requirements can be agreed upon in co-operation with the customer.

Test	Procedure	Sampling	Requirements
Mechanical dimensions	Dimensions are measured with micrometer screw or calliper gauge depending on the size		Depends on dimensions and the product type. In most cases ±0,1 mm or ±2%, whichever is the largest.
Displacement	Displacement at maximum recommended voltage measured with LVDT	AQL 0.65	Depends on dimensions and product type. In most cases displacement within ±15% of specified value.
Capacitance	1kHz; 1,0Vrms	100%	Depends on dimensions and product type. In most cases capacitance within ±15% of specified value.
Dielectric loss factor	1kHz; 1,0Vrms	100%	Depends on dimensions and product type. In most cases dielectric loss within ±15% of specified value.