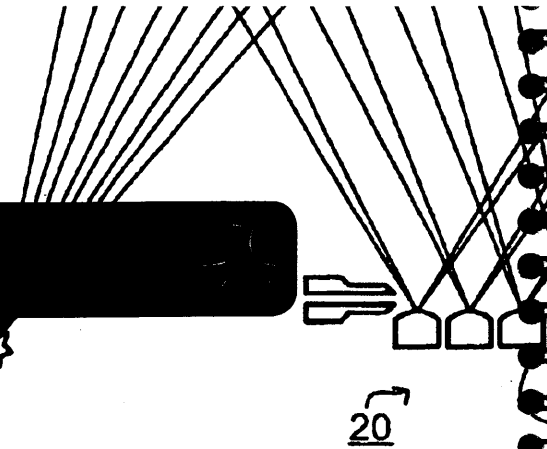
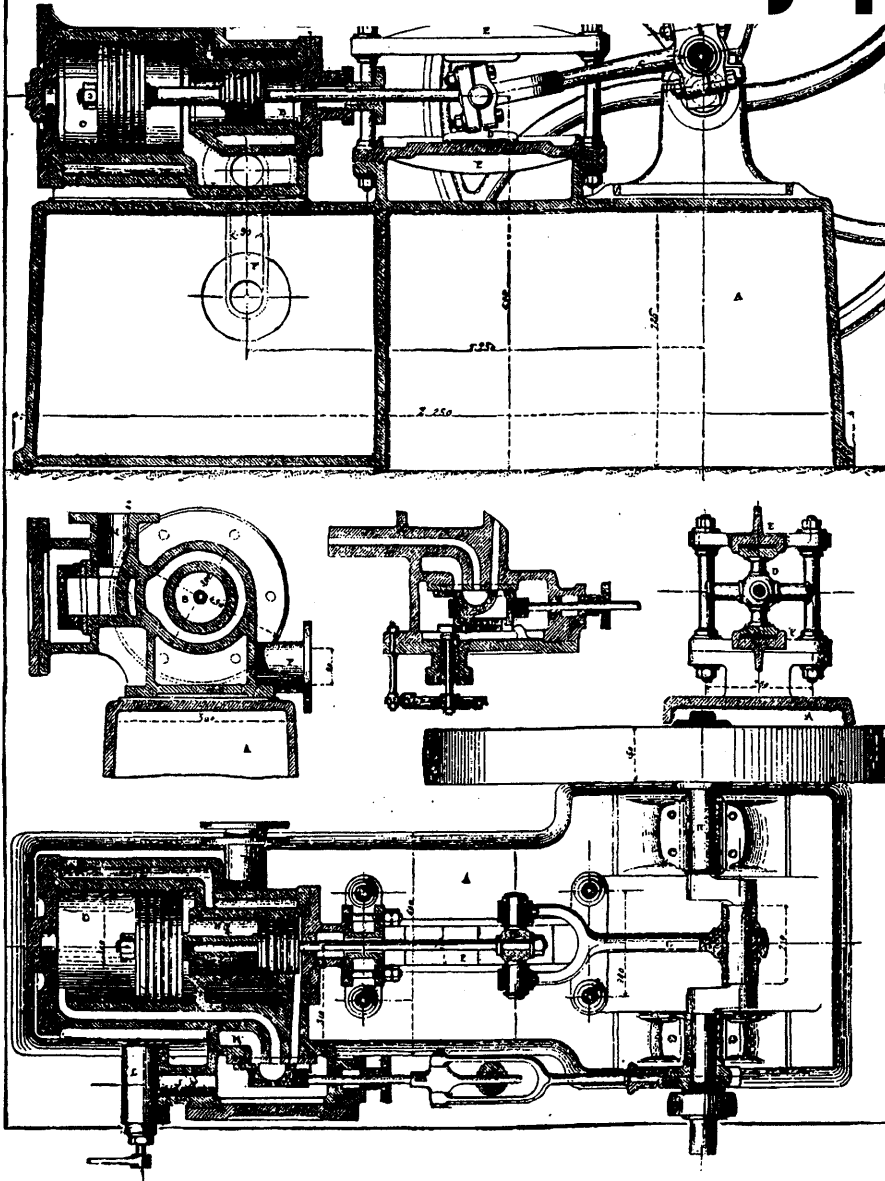


# Design: an evolutionary process

Florian Bociort



'We're entering the area where the dividing line between science and design becomes blurred. We use design as a scientific subject. Science is based on general rules and aims to simplify a problem, to smooth out the complications. But I think complications are essential and they can contain fundamental new things.' Dr Florian Bociort of the Optics Group designs lenses – no ordinary lenses but complex groups of them for use in wafer steppers, the machines that make chips. The group of lenses, or objective, needs to reduce a complicated mask to a chip with high-precision 70nm details using UV light. Geometrical optics is used to design lenses of this kind.

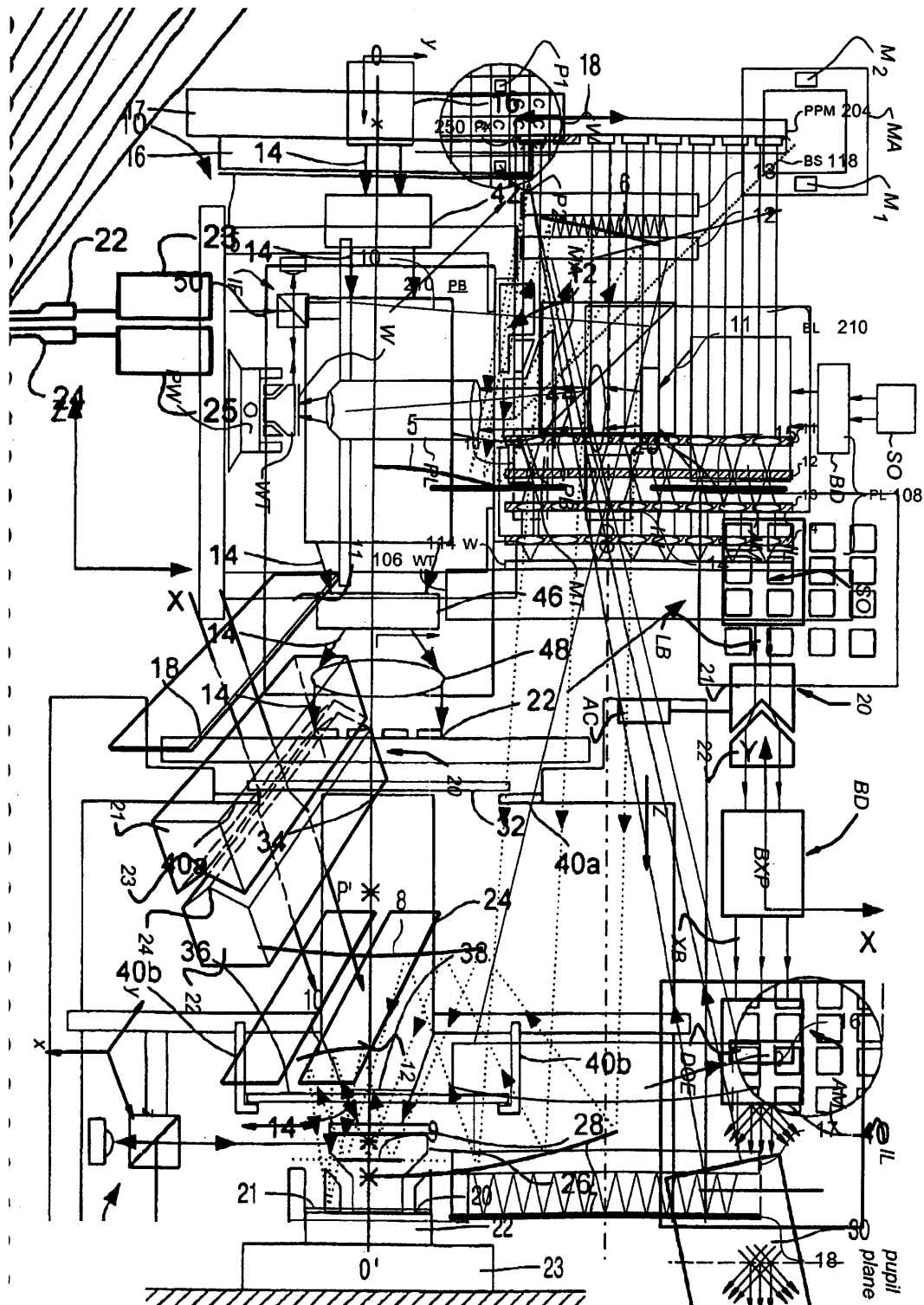
Bociort likes to quote Nobel prize winner Richard Feynman: 'geometrical optics is either very simple or very complicated.' Bociort is concerned particularly with the complex side of optics, where finding optima in the properties of groups of lenses is complicated and takes a lot of computing time, even with the fastest computers. 'Because it's so difficult it's partly a question of science and partly a question of art. Our design is a fusion of the two.'

A design is usually regarded as an end-result, but for researchers at a university the method by which that end-result is achieved is very important, in Bociort's opinion. 'Scientific knowledge naturally influences a

design: no-one will disagree with that. But conversely, a design can influence science. In a design a few unusual elements can together possess special properties, which can shed fresh light on science.'

The steam engine is a good example of that, Bociort opines. It was born from the first law of thermodynamics (the total quantity of energy in an isolated system is constant). But in their quest to keep increasing its efficiency, engineers stumbled upon limits that eventually led to a fundamental new insight, the second law of thermodynamics (entropy cannot decrease in a totally isolated system).

Optics design is very important to industry. Lithographic lenses, for example, have made it possible to produce cheap computer chips. A processor is made up of lots of layers that have to be written in detail. Printing structures 70 nanometres in size on some five hundred square millimetres in a very short time requires a gigantic quantity of information, comparable to the contents of 300 DVDs per second. Getting that information to the right place with as little distortion as possible demands machines that each costs many millions of euros with an objective costing a few million. One such objective contains twenty or so lenses.



'The design of these groups of lenses must meet certain criteria. If it's not possible to match the specifications you can increase the number of lenses,' Bociort notes, 'but that increases the price of the system and at the same time affects other properties of the lens group. Once upon a time they used to be designed using a lot of trial and error. If a lens did not come up to scratch it was thrown away. Now we use computer models. There are few areas where computer models work so well as in geometrical optics.'

Optics design is – as in many designing processes – an inverse problem: in other words, the client lays down certain requirements for image quality and the designer has to find the appropriate lens system. That is more difficult than doing it the other way round. 'We start by designing a system on the computer that doesn't meet the criteria yet, then we keep optimising it. That enables us to find local optimum points easily, the "local minima" of a function that describes the representation errors, which are close to the configuration you already have,' says Bociort.

'But it may be that there is a much better optimum that can be found a little further away. If you're only looking for local minima you'll miss that point, where the lens group performs much better. You can get the computer to look for those more distant minima, but using general methods from mathematics the computing time increases exponentially with the number of lenses, and it stops being a practical proposition very soon. That's why design in optics is still a combination of intuition, your own and other people's previous experience – as set out in patents – and a lot of trial and error on the part of both man and machine.'

Bociort and his colleagues have a smart trick for finding other minima for a particular group of lenses more quickly, however. By adding and removing lenses the PhD student Oana Marinescu found a new solution that was much better than the

optimum found so far. The same lens properties could be achieved with three lenses fewer than before. So substantial improvements can be achieved that – given the high cost of each lens – could be important to industry.

During this exercise to find optimum lens combinations, Bociort discovered something unusual. Adding one lens to an existing system in a special way creates a 'saddle point' in the computer model. From that point there are two routes to different minima, or optimum performances, for the lens group. 'At the saddle point the design path forks in two directions. If the procedure is repeated, each direction leads to a new saddle point where the path forks again. It's a bit like the branching points we know from evolution, where new species develop from common ancestors.'

The remarkable thing, however, is that in many cases what is ultimately the best solution for the lens group can be reached along different paths with their own saddle points. 'We call that kind of development "convergence", where different paths lead to the same, correct, solution. We find that in evolution too,' says Bociort, showing me two pictures of an eye, the human eye and a squid eye. The two eyes look awfully similar, although there are very few similarities between humans and squid.

'The squid eye evolved in a totally different way from the human eye. There's no common ancestor with eyes between the two kinds, and yet evolution arrived at almost the same design. In other words, evolutionary convergence produced the same solution. Is it a coincidence that we find this convergence process both in nature and in optics? It would be worthwhile to find out,' Bociort opines.

Bociort does not want to go too fast, as his ideas are still merely a hunch, a working hypothesis. He shows me a book about convergence in nature. 'Convergence in nature can be found in various places, but evolutionary biologists don't have an adequate explanation for it. In optics we can explain

how convergence comes about, why the various saddle points point in the same direction. I think the design process in optics is only one degree away from evolution.'

The example of the lithographic lenses shows how a practical design can aid in the understanding of fundamental problems. In this case we have saddle points where paths branch off in the direction of new local minima. The local minima are connected to one another by networks. 'We cannot say that this is the ideal solution to the design of lens groups,' Bociort warns, 'but it is a way to bypass the use of brute force, by powerful computers that have not yet

been invented. It can increase the efficiency of the work process.'

Do the branching-off, convergence and networks of local minima also occur in other design processes? 'I don't think it's likely to be a general principle,' says Bociort. 'It probably only occurs in special cases. But I do expect there to be more cases than just in biology and optics. Perhaps it can also be seen in the establishment of a new economic equilibrium following the introduction of the euro. The only thing we have discovered so far is that there are parallels and we don't know whether or not they are coincidental. The question, of course, is whether you

can predict whether a system will meet the criteria for convergence. We don't in any event have way of testing that in existing systems.'

Parallel to increasing the efficiency of the steam engine, which resulted in a limit on the conversion of heat into motion being found, there is also a fundamental limit in lithography, Bociort thinks. 'But the practical limits on resolution and the quantity of information that can be transferred by means of a lens system are still being increased. If we approach practical problems without being scared off by the real-world problems, the complexity of reality, we sometimes find very nice pieces of science.'

Bociort says without batting an eyelid that what the optics design team at TU Delft is doing is unique in the world. 'That's not so difficult,' he explains apologetically, 'there's hardly any research like ours going on at universities nowadays. There's a feeling that we already know all there is to know about geometrical optics. When professors retire they are not replaced, despite the fact that optics design is still very important in industry. In effect, we're the last of the Mohicans in academia. I think that's a mistake, though, as we're now entering the area of classical optics that Feynman says is very complicated.' ●

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