VacSim

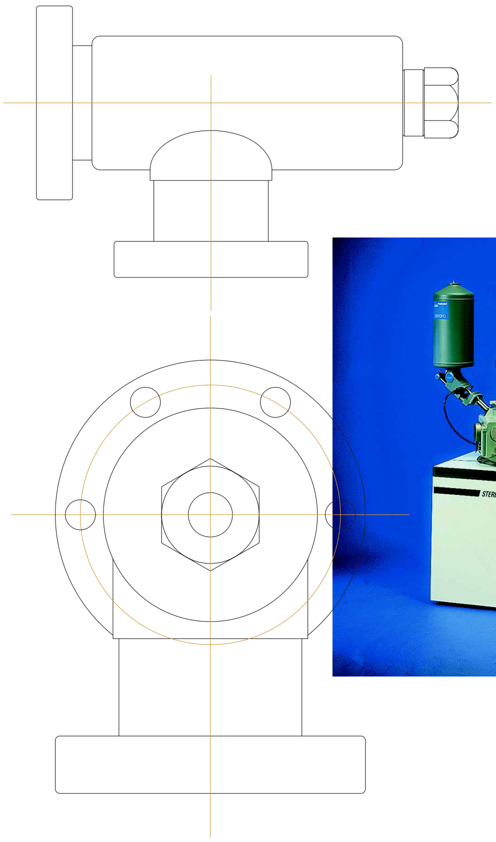
High Vacuum System Design & Simulation
Version 1.0

High Vacuum System Designers must often commit to building a system with no prior knowledge of the dynamic performance. The only prediction available is a rule-of-thumb one for ultimate pressure level, at a single physical location within the system. This traditional approach to high vacuum design usually leads to non-optimal performance, and almost always results in costly over-engineering.

Using VacSim you can have good dynamic prediction of pressure level variation with time at any chosen set of locations within the system, as pump down proceeds. Several other performance parameters are available besides pressure (e.g. throughput, control logic levels or oil migration). A mixture of simulation parameters can be chosen.

Benefits of using VacSim to assist design are:

- **better realised vacuum performance**
- **lower construction or manufacturing cost**
- **quicker experimental results for researchers**
- **less time to market for manufacturers**
- **superb teaching & training aid.**



A NEW CAPABILITY

VacSim will show you the performance of a high vacuum system with no need to buy any vacuum equipment and no need to build anything at all.

This software enables you to **design** your system "schematic" on screen, using the "symbols" and "models" of pumps, valves, pipes, outgassing, bakeout cycles and so on, which are provided for you in the software library.

Then click on **Simulate** and you will immediately start to plot (against time) on screen the parameter you have chosen, at the test point you have chosen. Most often this parameter will be pressure, but throughput, oil migration (from diffusion pumps), control logic levels and other parameters can be stipulated.

The parameter plots are self scaling and appear in "real time" as the simulation proceeds. You can use multiple simultaneous plots to show a choice of parameters at several selected test points.

We want to design the high vacuum system quickly, and simulate its performance easily, so the design is entered as a "schematic", that is with the minimum necessary information. A schematic consists of the component symbols (each of which represents a vacuum component part and has associated with it a "model") and the logical connections between them ... and nothing else. It does not include component dimensions (except where you are required to enter them, for example the radius and length of a cylindrical pipe because these determine the pipe's conductance), or the physical framework on which the system rests. It does include essential control logic.

VacSim has been designed for use by individual scientists and engineers working in industry, research institutes, colleges and universities and is also readily usable by a mechanical designer with a basic grasp of high vacuum design.

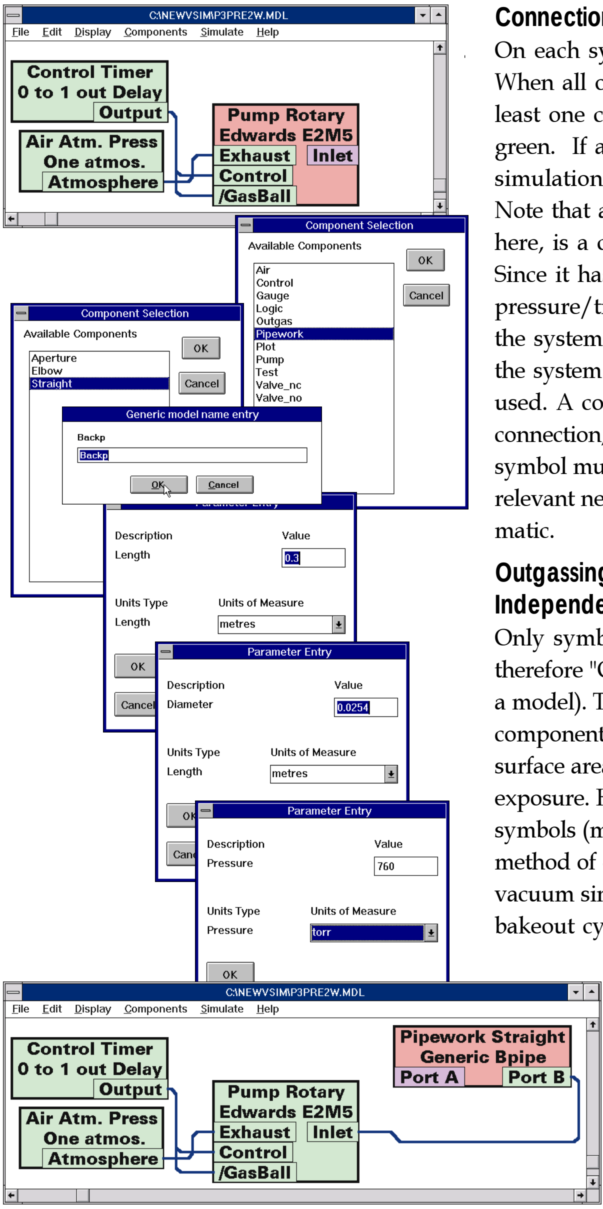
Components and Models

Each vacuum component in the library has an algorithmic physical "model" and a graphical "symbol".

The physical model dynamically simulates the component' s behaviour for the instantaneous local pressure regime, for any and all viable regimes. The model behaves during the simulation, instant by instant, in a fashion appropriate to the conditions in which it finds itself.

Thus, for example, a pipe behaves differently at atmospheric pressure (viscous flow) and at high vacuum when molecular flow applies.

The "symbol" represents this model on the screen, during schematic design. The default symbol is a rectangular red box which holds the name of the model and shows whether it is a generic model or a manufacturer's model. Where appropriate, models provide a series of drop down data entry boxes on screen so that you can enter information about the behaviour of a particular chosen pipe, pump, volume or other component.



Adding & Specifying the pipe "Backp" in the SEM example on the facing page. Click on a position in the schematic at which you wish the component to appear, select Components from the menu, then follow through the drop down box sequence which prompts you for the necessary data. Finally connect the new pipe. It remains red in the schematic because one port is not yet connected.

Connections

On each symbol are connection points. When all of these points are occupied by at least one connection the symbol turns green. If any symbol remains red the simulation cannot begin.

Note that a pipe, in the terminology used here, is a component and not a connection. Since it has finite conductance it affects the pressure/time relationship in other parts of the system and this behaviour forms part of the system simulation, so a pipe model is used. A connection is a pure logical connection, therefore each end of the pipe symbol must be logically connected to its relevant neighbouring symbol in the schematic.

Outgassing with Multiple Materials at Independent Temperatures

Only symbols and connections are allowed, therefore "Outgas" is a symbol (and thus has a model). The designer can select (for each component) the outgassing material, its surface area, temperature and history of gas exposure. He can attach multiple outgas symbols (models). This gives a very powerful method of dealing with a difficult problem of vacuum simulation. It caters for different bakeout cycles, different histories of exposure to air, and for multiple different materials within the same volume.

Superb "What-if?" Design

Symbols are placed, and connections made, with great ease and speed. Therefore the software is supremely productive for "what if?" design and simulation.

Vacuum calculator software has existed for some years, but has suffered always from its rigidity. Only ultimate pressures could be calculated, with no pumpdown simulation. Very tight design constraints were placed on the system configurations allowed, and the DOS user interfaces were very clunky. VacSim has a superbly usable custom interface which capitalises on the graphics flexibility, speed and precision which can be achieved using Windows with modern processors.

How VacSim is used - an illustrative example

VacSim gives you a tool which has not existed previously, so to illustrate its use the facing page shows a simple application example of how the high vacuum schematic design of a scanning electron microscope (SEM) can be completed, using multiple simulations to iterate to a satisfactory design in 10 to 15 minutes. **The software can be used for simulation and design of any type of demountable vacuum system, for example semiconductor process equipment, industrial plastic coating equipment or space simulation chambers (see box on back page for more examples).**

The design criteria for the SEM example are that the pressure values at certain specific locations are brought below the design maximum values within the stated pump-down times, and that the component and assembly costs are kept below the targets.

When you have an optimised vacuum design the schematic diagram, the simulated performance plots and the vacuum system parts list can be printed out. If the system is to be engineered for manufacture these documents can be presented to mechanical and electronic designers as the starting points for their designs.

Pictorial Displays, Clipboard, Printing

The standard schematic display allows rapid design entry and modification. Both schematic and plotter windows can be exported via the clipboard or printed to Windows printers. Alternative, "bitmap" displays using pictorial icons can make complex schematics easier to understand, and can be included in reports.

The (mathematical) model of a vacuum component is written in a format compatible with the SPICE simulator developed by the University of California at Berkeley. Traditionally, SPICE simulators (which work by solving a set of simultaneous non-linear differential equations) are used to solve for Voltages and Currents in electronic circuits. There is an exact parallel for Voltages with vacuum system Pressures, and Currents with vacuum system Throughputs. VACSIM exploits this isomorphism to simulate pumpdown performance.

SPICE has been refined through many generations and is established as by far the most widely used analog electronic simulator. VacSim builds on this legacy, and thereby avoids the years of teething troubles which might otherwise be expected in such new and original simulation software.

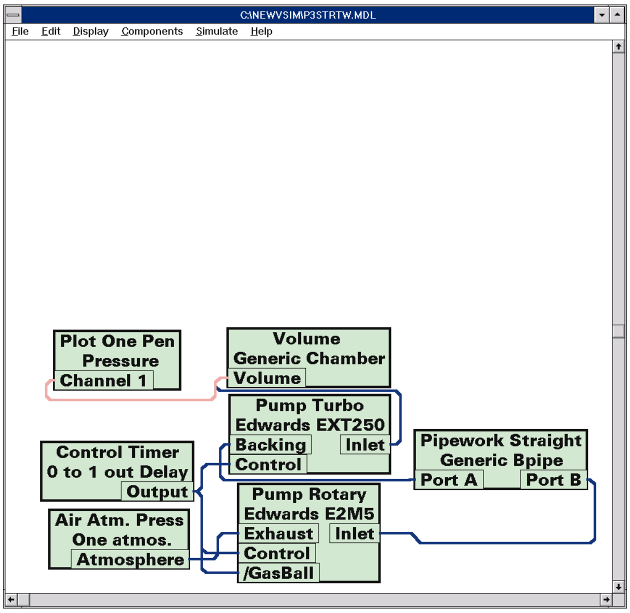
It uses a SPICE simulator program (the "SPICE Engine"), carefully crafted for this specific application from release 3F4 of Berkeley SPICE. The SPICE Engine solves for the pressures and throughputs in a series of time steps and passes back the results of each time step to a set of Plotting windows which VACSIM generates for the set of user selected test points . The data values are plotted in these windows "on-the-fly" (and with autoscaling of both axes) so you can monitor the simulation as it proceeds.

Events can be triggered by pressures crossing threshold values, on elapsed time or on logical combinations (AND, OR, NOT) of these conditions.

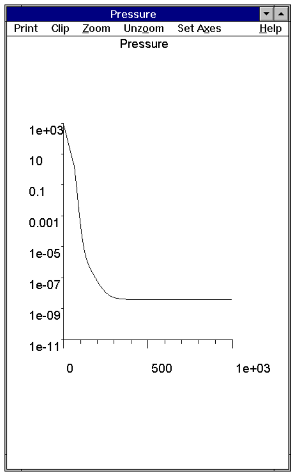
The SPICE models of most vacuum components in VacSim are "physical" models rather than "parametric" models. A physical model of a vacuum component has processes occurring within it which are isomorphic with the flow of gas in the component. In contrast, a parametric model is simply a "curve fit" to the performance data for the component over a specified region of its operation.

The main advantage of using physical models is that a large number of similar components can be represented by one underlying or "Generic" model. If you need a new model of a given type of component you can make one by substituting a small number of parameters, derivable from the manufacturer's data book, into the appropriate Generic model.

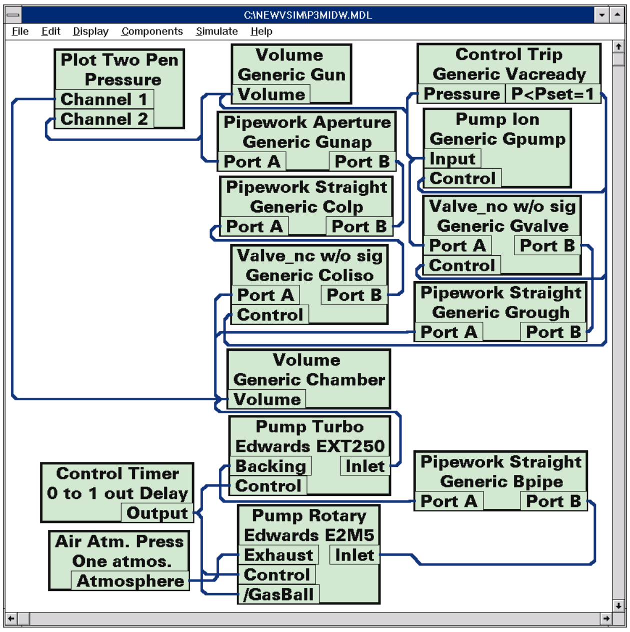
VacSim Example Application .... Scanning Electron Microscope High Vacuum Design



Start the schematic by placing the "Air" symbol with "Atm. Press" option, chosen from the Menu/Components/. Add the next component, a rotary pump, and connect its exhaust port to "Air". Turn on the rotary pump using a Control Timer Delay of 0 secs. Now add a rotary pump ("Edwards E2M5"), a straight pipe "Bpipe" (enter length and diameter), a turbo pump ("Edwards EXT250") a 10 litre volume ("Chamber") and a single pen plotter. This completes a first phase which can be simulated . <u>It is good practice to build up the design by testable stages to check for errors</u>.

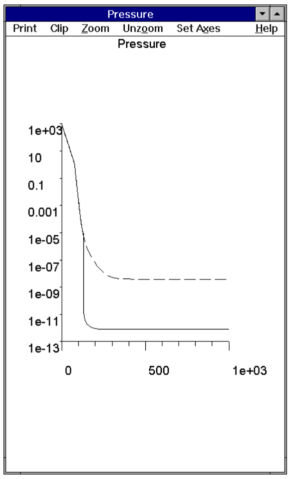


Log Chamber pressure (in torr) is shown plotted against time in seconds.

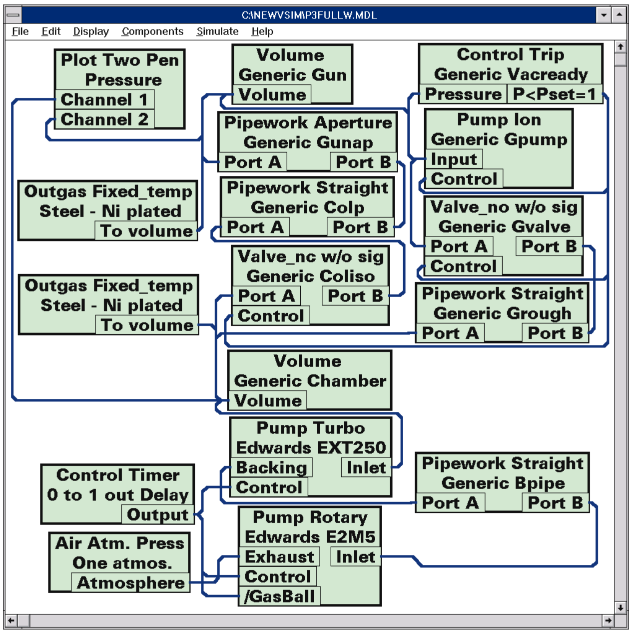


Add a column isolation valve ("Coliso"), a pipe ("Colp") to model pumping through the electron optical column , and a 1 litre volume for the electron gun. Replace the single pen plotter with a two pen plotter to show chamber and gun pressures simultaneously. Add a small aperture ("Gunap") between Colp and the Gun, a roughing pipe ("Grough"), with normally open valve ("Gvalve") which is tripped <u>closed</u> when the Chamber pressure falls below 10^{-5} torr, and an ion pump ("Gpump"), which is tripped <u>on</u> at the same pressure.

Note the effect of the ion pump and differential pumping aperture. After the gun roughing valve closes, the chamber and gun pressure curves separate. <u>Both curves are unrealistically flat after initial pump down (and the pressures unrealistically low) because outgassing has not yet been included.</u>

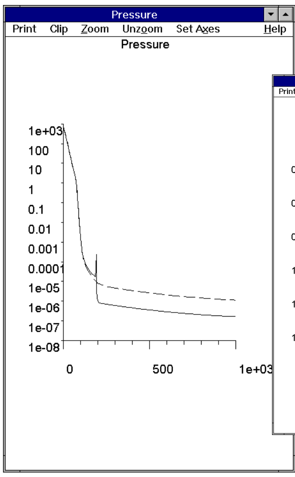


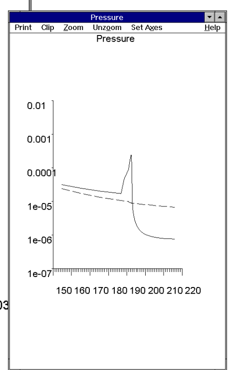
Log Chamber pressure & log gun pressure (no outgassing).



Add nickel plated steel outgas models to each of the chamber and the gun volumes.

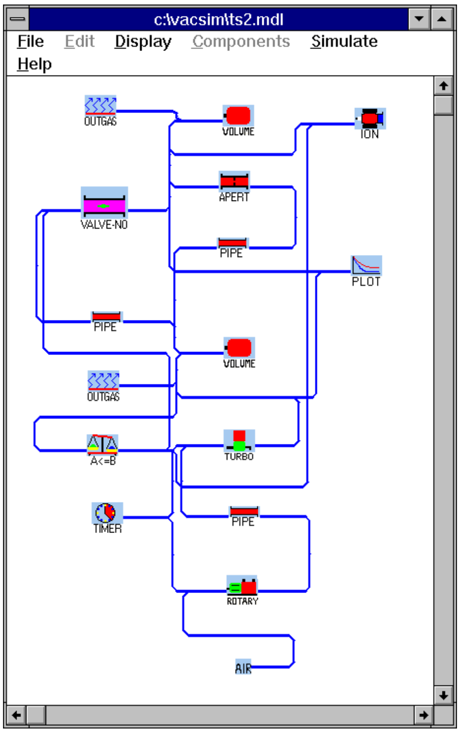
The final simulation shows the effects of outgassing on the pressure curves. Note especially the spike caused in the Gun pressure curve by the evolution of gas after the gun roughing valve has closed, and before the ion pump has fired up. This could be designed out by delaying valve closure. Bakeout cycles are easily simulated, using the "bakeable outgassing" model.





<u>Zoomed</u>

Log Chamber pressure & log gun pressure with outgassing.



The System Bitmap display gives an easily understood pictorial view of the complete high vacuum system.

```
Notepad - ts2.TXT
File  Edit  Search  Help
Vacsim Model Report for ts2.mdl

Created on: September 14, 1995

Control    Timer
0 to 1 out   Delay
Delay : 0 seconds (Time)  Editable
Ontime : 0 seconds (Time)  Not Editable
Repeat : 0 seconds (Time)  Not Editable


Plot    Two Pen
   Pressure
Min. Time : 0 seconds (Time)  Editable
Max. Time : 1000 seconds (Time)  Editable
Time_Log(1)/Linear(0) : 0 logic (Dimensionless)  Editable
Time_AutoScale(1) : 1 logic (Dimensionless)  Editable
Min. Pressure : 1e-10 atmosphere (Pressure)  Editable
Max. Pressure : 1 atmosphere (Pressure)  Editable
Press_Log(1)/Linear(0) : 1 logic (Dimensionless)  Editable
Press_AutoScale(1) : 1 ratio (Dimensionless)  Editable


Pump    Rotary
Edwards   E2M5
Compression Ratio : 1e+07 ratio (Dimensionless)  Not Editable
Initial Pressure : 1 atmosphere (Pressure)  Editable
Pump Rate : 1.39 litres per sec (Pump Speed)  Not Editable
Diameter : 0.025 metres (Length)  Not Editable
CRgasball : 33000 ratio (Dimensionless)  Not Editable


Air    Atm. Press
   One atmos.


Volume
Generic   gun
Volume : 0.3 litres (Volume)  Editable
Initial Pressure : 1 atmosphere (Pressure)  Editable


Outgas    Fixed_temp
   Steel - Ni plated
Area : 300 Square cm (Area)  Editable
STARTING PRESSURE : 1 atmosphere (Pressure)  Editable
```

The top of the parts list file, automatically created for each schematic. The file can be printed out for mechanical and electronic design purposes. This Windows Notepad display shows the top 5 to 6 components of the parts list, together with their selected parameters.

Summary Specification

- High vacuum system schematic entry using included generic symbol library with custom designed GUI
- Simulation of parameter variation with time for each of a set of user selected test points, using a corresponding set of auto-launched, auto-scaled plotter windows; parameter can be chosen separately for each plot window; axes can be lin/lin, log/lin, lin/log or log/log)
- Range of plottable parameters includes at least:
  - pressure
  - throughput
  - pumping speed
  - logic level
  - oil cumulative mass or oil mass/unit time (for diffusion pumps)
- Range of models and symbols in library (mostly generic, but also some manufacturers' models) includes at least:
  - volume
  - air
  - rotary pumps
  - dry pumps
  - booster pumps
  - turbo pumps
  - diffusion pumps
  - diffstak
  - valves
  - pipes
  - apertures
  - control and measurement elements and devices e.g. timers, heaters, AND, OR, NOT gates, gauges, pressure level trips
- Automatic units conversion - when parameter units are changed the parameter value is automatically converted to the new units.
- Outputs (in addition to screen plotters) are:
  - high vacuum schematic designs to Windows printers and Clipboard or Clipbook
  - plot windows to Windows printers, Clipboard or Clipbook
  - Parts List text file which is automatically generated each time a simulation is run, and from which a Parts List for the high vacuum schematic design can be printed.

System Requirements

Software Requirements:

- VacSim runs under Microsoft Windows V3.1, Windows for Workgroups V3.11, Windows 95 or Windows NT Workstation V3.5 or later.
- WIN32s (If you do not already have WIN32s installed, VacSim will install it for you).

Hardware Requirements:

- Personal computer with a 386DX, 486DX , Pentium or Pro Pentium Processor.
- A maths co-processor is not mandatory, but the simulation time will then be extended greatly for all but the simplest of high vacuum systems. A co-processor is strongly recommended.
- 8MB of RAM
- Available hard disk space:
  - 1.5MB for executables
  - 2MB for Win32s (not NT or W95)
  - 4MB of Swap space
- A 3.5" high-density disk drive
- Microsoft Mouse compatible pointing device
- VGA or higher resolution monitor

Engineering Applications

Scientific Instruments
Space Simulation Systems
Vacuum Coating, Sputtering & Plating
Semiconductor Production Equipment
Ion Beam Implanters
CVD Equipment
Molecular Beam Epitaxy
Cluster Systems
Industrial Plastic Coating Process
Electron Beam Lithography
Electron Beam Curing
Cathode Ray Tube Production
Microwave, Audio etc. Tube Production
Any demountable high vacuum system.

Educational & Training Applications

Vacuum design tutorial courses
On the job self training
University and college training in high vacuum technology

The LC430i Scanning Electron Microscope photograph reproduced on page 1 is reproduced with the express permission of Leica Cambridge Ltd. The drawings of a UHV valve on page 1 were available on the VG World Wide Web Home Page.

Technology Sources Ltd., 2 Signet Court, Swanns Road, Cambridge CB5 8LA, United Kingdom
Telephone: +44-1223-516469 (International), 01223-516469 (UK)
Fax: +44-1223-729916 (international), 01223-729916 (UK)
E-mail: info@softsim.com