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Check and Stop-Check Valves for High Turndown Applications

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Check And Stop-Check Valves For High Turndown Applications

E. A. Bake,
Research Manager,
Edward Valves
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ABSTRACT

Some applications of check and stop-check valves involve a high ratio of maximum to minimum flow (high turndown) in normal operation. This may involve (1) risks of damage due to instability at lowest flows, (2) excessive pressure drop at the highest flows, or both. Choice of the wrong valve for such applications can be a costly mistake. Instability at low flows may incur wear and maintenance costs, as well as associated costs due to outages; high pressure drop will incur energy costs due to excessive pumping power requirements.

Where a high turndown requirement exists, care should be taken in selecting the best possible check valve type and size. In some cases, special design features, such as skirted disks, may be necessary to provide the best compromise between I low and high flow performance. Control with stop-check valves or parallel valve installations for high and low flow ranges may be necessary in extreme cases.

Introduction

Check valves have a history of neglect in the design and construction of fluid systems – in power plants, refineries, and in general industry. Many valves are sized just to match the connecting pipe, and check valve types are often selected based only on minimum price. In spite of this neglect, problems are usually not common or serious. Nevertheless, there are a number of chronic types of check valve problems, and serious difficulties arise occasionally. Edward Valves has conducted many flow tests of check valves, starting in the 1940s, and applications guidelines on larger valves have been published in catalogs and flow handbooks for many years. More recently, a comprehensive test program and performance prediction study was conducted [1]* on a broad range of Edward check valve sizes and types, and a comprehensive set of guidelines for applications of both large and small check and stop-check valves is provided in the current Edward Valve Catalog and Application Manual [2].

General Check Valve Sizing Guidelines

A common check valve problem is sizing based on "matching the pipe". Some piping systems are sized conservatively based on old "handbook rules" that were devised to minimize velocity and possible erosion and noise problems. If economics are not scrutinized carefully, 8-inch NPS pipe may be used where 6-inch pipe would be adequate. Except for cost, this may be harmless for pipe but undesirable for check valves.

This practice often leads to an oversized check valve; a large valve not only costs more to begin with, but it can also lead to wear and maintenance expenses if the valve operates partially open most of the time. Flutter due to flow instability or vibration from external sources can cause rapid wear of internal guides or bearings. In extreme cases, a check valve disk may just open for a fraction of its normal travel and bounce noisily on and off its seat – a condition likely to lead to early failure.

A check valve is a passive device that is opened by fluid dynamic forces acting on the disk. Preferably, check or stop-check valve disks should be fully open, securely loaded against disk stops during all flow conditions to minimize vibration and wear. Edward Check Valve Sizing guidelines [2] recommend that valves be sized to assure full opening whenever possible. In the specific case of tilting-disk check valves, Edward recommends that steady flow rates be 20% more than the minimum required for full opening to preclude "tapping" against stops if the valves are close to an upstream flow disturbance; equalizers on piston-lift check and stop-check valves preload disks against stops when fully open and provide inherent resistance to such tapping.

Using Edward sizing methods, it is relatively easy to size valves for full opening in applications involving relatively constant flow rates during all plant or system operating conditions. However, some piping systems with check valves undergo a broad range of flow conditions in going from startup to full load – and then sometimes to partial load and standby conditions. A check valve sized to be fully open at the lowest flow rate may be <u>too small</u> and produce excessive noise or pressure drop at the highest flow.

When a check valve is needed for duties that involve a broad range of flow conditions, it is called a <u>high turndown application</u>. The normal industrial definition of turndown is simply:

•Numbers in brackets designate references listed at the end of this paper.

Check And Stop-Check Valves For High Turndown Applications

$$\text{TURNDOWN} = \frac{\text{MAXIMUM FLOW RATE}}{\text{MINIMUM FLOW RATE}}$$

A common example of "turndown" problems arises on boilers, so this application will be used for many of the following discussions. It should be understood, however, that similar cases arise in many other industrial process systems (e.g. chemical plants, refineries).

At one time, a turndown ratio of 4:1 was commonly encountered in many normal package or industrial boiler applications. It described the range of steam flow rates that could be accommodated without instability or "flameouts" in normal operation. Feedwater and steam check valves normally gave satisfactory service in these applications if they were sized properly.

However, trends in the past decade or more have been toward ratios in the order of 10:1. This has become particularly common in peaking power plants and COGEN units that have to respond to broad variations in load. Some industrial boilers have to swing from standby to full-load operation once a day or even more often. New control technology has improved the ability of boilers to operate successfully over broader flow rate ranges, but this presents challenges for check valves.

While the simple flow rate ratio above defines turndown, check valve operation is influenced by both flow rate and fluid density. Startup conditions may involve different pressures and temperatures than full load or other operating conditions (sometimes there is liquid flow under some conditions and gas or steam flow at others).

For evaluation. of high turndown applications, a slightly more complicated ratio is helpful. Edward recommends that a <u>Valve Sizing Parameter</u> be calculated for each identified normal flow condition:

NOTE: *Readers may find it useful to refer to Reference 2 at this point for better understanding of the following discussion.*

$$SP = \frac{w}{\sqrt{\rho}}$$

where: SP = Valve Sizing Parameter

w = Weight Flow Rate – lb/hr or kg/hr

ρ = Weight density of fluid at valve inlet conditions – lb/ft^3 or kg/m^3

For the purpose of this paper, a new ratio will be defined as:.

$$SPR = \frac{SP_{MAX}}{SP_{MIN}}$$

where: SPR = Sizing Parameter Ratio SP_{MAX} and SP_{MIN} are maximum and minimum sizing parameters calculated from all normal flow conditions (U.S. Customary or Metric Units)

It is very difficult to size check valves to meet the fundamental goal of achieving full-open operation under all conditions in high turndown applications. Partial opening at lower flow rates often has to be accepted. Special procedures and, in some cases, specialized valve features may be required to assure trouble-free service.

Check Valve Selection for High Turndown.

As indicated above, the limitations in high turndown check valve applications are:

- **Freedom from damage due to disk flutter and disk-seat impact at lowest flow conditions**
  Where a check valve must operate partially open for part of its duty cycle, Edward recommends that the disk lift or opening be not less than 25%. Extensive tests have shown that many check valves operate in a stable manner at smaller openings if flow is stable, but there is a risk of valve instability if there are flow pulsations or disturbances from other equipment (e.g. pumps). Maintaining a lift in excess of 25% reduces the risk of damage due to instability.

  Obviously, valves that achieve 25% opening with low "sizing parameters" are attractive in high turndown applications.

  CAUTION: *Any check valve that operates for sustained periods at partial openings should be monitored or inspected periodically for evidence of wear.*

- **Freedom from excessive pressure drop, noise, and velocity at highest flow conditions.**
  High pressure drop has serious economic implications, particularly in cost of pumping power. Obviously, check valves should be sized to be fully open at highest flow rates. Valves that offer a high flow coefficient (C_V) when fully open offer a sizing advantage. Valves sized for acceptable pressure drop rarely produce significant flow noise.

Fluid velocity is rarely a limitation if pressure drop is not a problem, but erosion-corrosion of carbon steel valves has been observed at relatively moderate velocities with certain water chemistry conditions (particularly in nuclear power plants).

While Edward procedures urge check valve sizing for full opening when practical, extensive testing has provided bases for predicting check valve disk position at partial openings. The key to this procedure is the normalized sizing parameter:

$$R_F = \frac{SP}{SP_{FL}}$$

where: R_F = Normalized Sizing Parameter

SP = Sizing Parameter as defined above

SP_{FL} = Sizing Parameter for Full Lift for Selected Valve (tabulated in Edward Catalog [2])

In evaluating a check valve for a high turndown application, it may be first sized to be fully open at maximum flow by selecting a valve with SP_{FL} less than $\underline{SP_{MAX}}$ as defined above. Then, after calculating RF at $\underline{SP_{MIN}}$, the "Percent Open" may be read from an appropriate graph in the catalog. This practice may be repeated with various valve sizes or types until one is found that gives an acceptable compromise of minimum disk opening and maximum pressure drop.

This practice may be easier to understand through review of the following example (refer to Reference 2, which describes the procedures employed in this and other examples):

Example 1

NOTE: *All details of calculation steps will not be shown here in interests of brevity. Readers are urged to study EV-100. Examples in this paper are in U. S. Customary Units. EV-100 permits solution of problems in metric units as well.*

Problem: Select a check valve for the following boiler feedwater application and determine valve position and pressure drop at each flow condition:

Design Conditions: 2400 psig at 325°F

Operating Conditions:

(1) Full Load: 685,000 lb/hr, 2250 psi. at 300°F, Maximum pressure drop –10 psi

(2) Standby: 150,000 lb/hr, 2350 psig at 250°F

TURNDOWN = 685,000/150,000 = 4.6

Solution: The solution is a step-by-step process that may require trial-and error work.

1. From the design conditions and ASME/ANSI B16.34–1988 requirements (page H 10 of Reference 2), a class 1500 A–216 WCB carbon steel valve is desirable. Figure 7594Y piston lift globe (90° bonnet) check valves will be evaluated.

2. Calculate Sizing Parameter Ratio (SPR)

   SPmax = 90,100
   SPmin = 19,480
   SPR = 4.6

3. Trial (1):

   From Table 10 of Edward catalog EV-100, <u>select size 8</u> Figure 7594Y which has:

   SP_{FL} = 59,300 (Selected as the largest size with $SP_{FL} < SP_{MAX}$)

   C_V = 790

   This valve would be fully open at full load, so the pressure drop can be calculated from catalog equation (1c) on page G 22 of EV-100. Assuming valve and line sizes are the same:

   DP = 3.2 psi

   The opening at standby must be evaluated:

   R_F = 0.33

   From performance curve I of Figure 17-B of the catalog, it may be seen that this R_F would produce a disk opening of less than 20%, so this valve *would not* satisfy the 25% minimum lift criterion at the standby condition.

4. Trial (2):

   Evaluate the next smaller Figure 7594Y globe piston lift check valve, <u>size 6</u>. From Table 10 of EV-100:

   SP_{FL} = 35,000

   C_V = 465

   The valve will be fully open at full load since SP_{FL} < 90,100, and, again assuming that the valve and line size are the same:

$DP = 9.4$ psi (full load)

At standby:

$R_F = 0.56$

From performance curve 2 of Figure 17-B (reference 2), it is apparent that even the size 6 valve would be only slightly more than 20% open at the standby condition and would not satisfy the 25% minimum lift criterion. It is obvious that the pressure drop at full load would exceed the desired maximum of 10 psi with a smaller valve of this type.

5. Trial (3):

Evaluate a Figure 7592Y Edward Flite-Flow inclined bonnet piston lift check valve. Using Table 12 of EV-100, select a size 6 valve to get $SP_{FL} < SP_{MAX}$

$SP_{FL} = 51{,}200$

$C_V = 860$

$DP = 2.7$ psi (full load)

At standby:

$R_F = 0.38$

From performance curve 3 of Figure 19-B (reference 2), it is found that this valve would be approximately 30% open, satisfying the 25% minimum lift criterion.

The pressure drop of a partially open check valve is calculated from catalog equation (18) as follows:

$DP = R_P \, DP_{FL}$

where: R_P = Normalized Pressure Drop

DP_{FL} = Minimum Valve Pressure Drop for Full Lift, psi

From performance curve 3 of Figure 19-A (reference 2), at $R_F = 0.38$, read $R_P = 2.0$. From Table 12, $DP_{FL} = 0.89$ psi.

$DP = 1.8$ psi

This example shows that a change in valve type may be helpful in solving a turndown problem. In this case, use of an inclined bonnet Flite-Flow valve permitted a size 6 valve to be used with a lower full-load pressure drop than would have been possible with a size 8 90° bonnet globe design; in addition, the size 6 Flite-Flow disk would be more than 25% open at standby, whereas either the size 6 or 8 90° globe check disk would be less than 25% open and possibly subject to damage.

IMPORTANT. *This example provides a significant "helpful hint". Inclined bonnet Flite-Flow check and stop-check valves have significantly higher C_V values than 90° bonnet globe valves of the same size, so a smaller Flite-Flow valve may be used without excessive pressure drop at high-flow conditions. The smaller valve inherently contributes higher lift at low flow conditions.*

Furthermore, the performance curves 17-B and 19B (reference 2) show that Flite-Flow valves achieve the recommended 25% minimum lift target with lower R_F values (0.25 to 0. 3 for Flite- Flow valves versus 0. 4 to 0.7 for 90° bonnet globe valves). This is a second feature contributing to higher low-flow disk lift. Thus, in sizes and pressure class applications where available, Flite-Flow valves offer significant advantages for high turndown.

While the turndown in Example 1 (4.6) was moderate it has been found in practical cases that standard Flite-Flow valves can sometimes accommodate turndowns of up to 8 or 10, depending on the velocity and pressure drop allowable at maximum flow conditions. Actual values attainable vary because of increments between sizes available.

The beneficial features of Flite-Flow valves (high C_V relative to size and low RF values at 25% lift) are also found in most Edward tilting disk check valves and small forged steel valves (e.g. Univalves), so they also provide good characteristics for high turndown service.

Check Valve Disk Skirts for Very High Turndown Applications

For many years, Edward has employed "skirts" or extensions to the bottom of disks in piston lift check valves to "boost" disk lift at low flow rates. Figure 1 illustrates a globe check valve with a relatively long fabricated skirt assembly on the disk. These skirts were first used for field corrections of problems that occurred with oversized check valves. When a valve had been selected merely to match the pipe and had instability problems, a skirt made of pipe and plate could sometimes be added to open the valve fully.

It did not take high-technology hydraulic, knowledge to recognize that a skirt causes a restriction to flow at low disk lifts; this increases the pressure drop, which increases the lifting force. Providing that the increased lifting force exceeds the weight added by the skirt, the disk opens further. It was fairly easy to design a skirt that would make a valve perform like one that was one size smaller. As a correction for a field problem, simple skirts were effective, but they did not offer an economic solution for high turndown problems in new installations. The flow restriction from the skirt that helps at low flows and disk lifts can be costly at high lifts, increasing the pressure drop seriously at high flow rates,

An extensive parametric test program was conducted on size 4 and size 8 globe and angle check valves in the attempt to develop an optimized disk skirt geometry for high turndown applications. Disk skirts with various ratios of (1) skirt diameter to seat port diameter and (2) skirt length to disk lift were made and tested in water flow loops as described in reference 1. Test results provided disk lift as a function of flow rate and also flow coefficients (Cv) as a function of lift. Examination of results with the various skirt dimensional parameters permitted determination of dimensions that gave best results.

As expected, some disk skirts were <u>not effective at all</u> in increasing turndown capabilities. In some cases, the added weight of a skirt actually detracted from lowflow performance. However, a <u>Mini-Skirt</u> with optimized skirt diameter and length was developed from the extensive parametric test data (see Figure 2). The Mini-Skirt features provide an excellent balance of (1) high disk lifts at low flow rates and (2) minimum increase in pressure drop with the valve fully open at high flow conditions.

As compared to a valve with a standard disk, an Edward globe or angle piston lift check valve with a Mini-Skirt mall:

1. Provide a disk lift of 25% or more with a flow rate of approximately 16% or less of the flow required for full opening (RF = 0.16). The Mini-Skirt has no significant effect on the flow rate required for full lift, so calculations that show that a standard disk would be fully open would also assure full opening of the skirted disk.
2. Reduce the Cv at full opening by only approximately 10%. Thus, to calculate pressure drop of a valve with a Mini-Skirt, multiply the value given in the catalog for the standard valve by 0.9

NOTE: *Mini-Skirts are offered only for globe and angle type piston, lift check valves, and they should be used only in applications with the bonnet substantially vertical. The slight weight increase of the bottom of the disk could cause cocking or sticking with the valve tipped. The "orientation limits" in section 1.3 of catalog EV-100 do not apply.*

The actual disk lift and pressure drop of valves with partially open Mini-Skirt disks cannot be predicted accurately, but the tests showed th)at the disk tends to lift about 35% to 40% at flow rates above a low threshold. The slight increase of disk weight may produce a pressure drop as much as 20% more than would be calculated for a valve with a standard disk.

As a first illustration of a Mini-Skirt application, refer back to step 3 of the problem in Example 1 above. At the standby flow condition, the size 8 Figure 7594Y check valve with its standard disk would have been less than 20% open, thus not meeting the 25% minimum criterion. Note, however that the value of RF under that condition was <u>0.33</u>. Since 0.33 is greater than 0.16, a Mini-Skirt would produce <u>more</u>

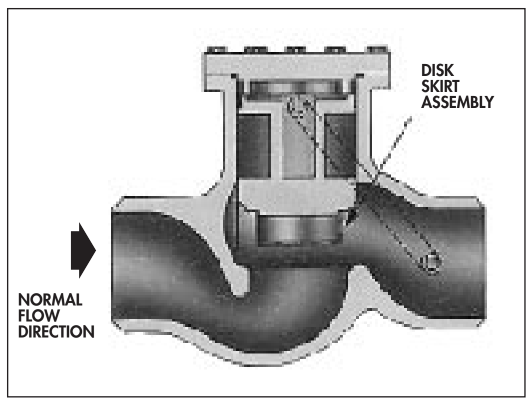

Figure 1: Globe Check Valve with Fabricated Disk Skirt.

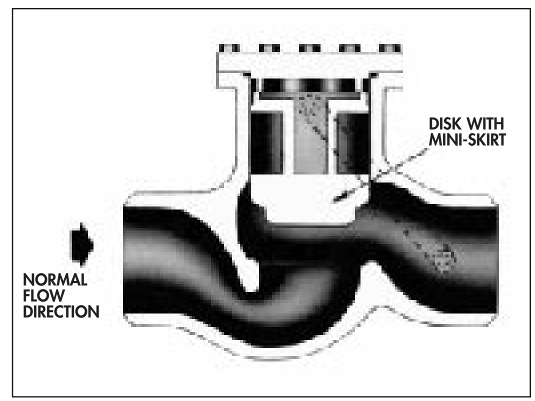

Figure 2: Globe Check Valve with Mini-Skirt on Disk for High Turndown Service

than 25% lift at the standby condition (see paragraph 1 above). However, by paragraph 2, the valve C_V will be reduced when the valve is fully open. Recalculation of the pressure drop at full load conditions shows that the MiniSkirt would increase the drop from 3.2 to 4.0 psi.

Note that the size 6 Figure 7592Y Flite-Flow valve selected in step 5 of Example I would offer both smaller size and less pressure drop than the Figure 7594Y valve with the Mini-Skirt. However, skirted disks offer significant advantages in lower pressure class applications, particularly when even higher turndown ratios are involved. Example 2 illustrates an application that might be encountered in a COGEN unit designed for moderate pressures and temperatures.

Example 2

Problem: Select a stop-check valve for steam discharge to a header in a multiple-boiler COGEN plant and determine disk position and pressure drop at normal and weekend conditions:

Design Conditions:	1600 psig at 925°F
Operating Conditions:	
(1) Normal	300,000 lb/hr 1500 psig at 900°F Maximum pressure drop –10 psi
(2) Weekend	30,000 lb/hr 750 psig saturated steam (513°F)

TURNDOWN = 300,000/30,000 = 10

Solution: Again, a step by step process will be used.

1. From the design conditions, a Special Class 900 valve of ASTM A-217 WC9 alloy steel valve will be selected. An Edward Figure 4306Y(WC9) stop-check valves will be evaluated for the application.
2. Calculate the Sizing Parameter Ratio:

   $SP_{MAX} = 209{,}000$

   $SP_{MIN} = 23{,}200$

   $$SPR = \frac{209{,}000}{23{,}200} = 9.0$$

Evaluate data for Figure 4306Y valves in Table 10 of reference 2.

Note: *Since this is a steam application, EV-100 guidelines recommend that tabulated SP_{FL} values be increased by 7% and DP_{FL} be increased by 14% to account for reduced disk buoyancy as compared to that in more normal water service.*

3. Trial 1:

   In Table 10, a size 14 valve (SP_{FL} = 211,000 x 1.07 = 226,000) would not be fully open at normal conditions by a small margin. Try size 12:

   SP_{FL} = 182,000 x 1.07 = 195,000

   Since 195,000 < 209,000, the size 12 valve would be fully open at normal conditions.

   C_V = 2000

   At normal conditions, from equation (1c) of EV-100,

   DP = 2.7 psi

   At weekend conditions:

   R_F = 0.12

   From performance curve 2 of Figure 17-B (reference 2), the standard valve would obviously be much, much less than 20% open. Also, since $R_F < 0.16$, the size 12 valve would be unacceptable even with a Mini-Skirt by the guidelines above.

4. Trial 2 –size 10:

   SP_{FL} = 119,000 x 1.07 = 127,000 (valve fully open at normal conditions)

   C_V = 1400

   At normal conditions DP = 5.6 psi

   At weekend conditions:

   R_F = 0.18

   From Figure 17-B of reference 2, it is again obvious that a valve with a standard disk would be much less than 20% open and unsatisfactory. However, since $R_F > 0.16$, the Mini-Skirt option would provide more than 25% disk lift at the weekend conditions.

   As discussed previously, the actual disk lift at the weekend condition cannot be predicted, but it would probably be over 35%. The pressure drop at this low flow condition may be estimated by procedures described in reference 2. This is rather involved and will not be detailed here, but the best estimate of the pressure drop under weekend flow conditions is 3.3 psi

Example 2 illustrates a case where a globe stopcheck valve with a Mini-Skirt disk can accommodate a turndown of 10 (SPR = 9). Actual cases where these special disks are used sometimes involve higher values, The Mini-Skirt has been applied in a substantial number of size 3 through 14 Edward check and stop-check valves. These valves have been well received, and field results to date indicate successful performance.

Solutions for Applications Involving Extremely High Turndown

Example 1 and subsequent discussions show how standard Edward Flite-Flow, tilting disk, and forged steel check valve characteristics can permit operation with turndowns in the order of 10. Similarly, Example 2 illustrated how Mini-Skirts on disks of 90° bonnet globe and angle valves also permit operation with turndown in the same range. Higher values may be obtained, particularly if increased pressure drop is acceptable at maximum flow rates. However, there are practical limits to the conditions that can be accommodated with any single passive check valve.

Some "extreme" turndown conditions arise under plant startup and shutdown conditions. Some valves have been reported to "slam" and "hammer repetitively" at lowest flow conditions, but often no problems occur if the duration of such operation is brief. If prolonged operation at extremely low flow rates is expected, special features or valve combinations may require consideration. It is difficult to generalize about such cases, but two possible approaches will be:

- Control with stop-check valve – On increasing flow, the stem of a stop-check valve can be opened slowly so that it always restrains the disk. Likewise, slow closure can be maintained as flow decreases. The key is to maintain enough pressure drop across the disk to be sure it is firmly loaded against the stem. This can be done manually in steps, but control is sometimes difficult. A control system with a motor operator may be economically justified in some cases.
- Use stop-check valve with small by-pass check or stop-check valve – By-pass valves are often required on gate valves and other stop valves to allow very low flow rates during heating of downstream piping. Such low flows could damage a check valve in the same line, due to bouncing on and off its seat. To prevent this, a stop-check valve may be used with a small check valve in a by-pass line (large stop-check valve held closed with stem at low flows to force flow through the small by-pass).

Summary

Check valve guidelines in the Edward Valve Catalog and Application Manual [2] are very complete, but some applications are relatively complex. This paper is an extension of the Edward guidelines to address high turndown applications in detail. While many of these are relatively simple, some require "custom engineering"; in unusually high turndown applications, consultation with Edward may be required for selection of the best valve and system approach.

High turndown check valve applications generally require part-time operation with disks not fully open. Long-term success requires attention to Edward recommendations [2] concerning preventative maintenance. Periodic monitoring or inspection is important in all check valves, and it is especially important where substantial amounts of of operation are with less than full opening.

References

(numbers in brackets in text):

[1] E. A. Bake. "Flow Performance, Stability, and Sealability of Piston-Lift and Tilting Disk Check Valves", Edward Valves Inc. Technical Article V-Rep 90-2.

[2] Edward Valves Inc. "Valve Catalog and Application Manual", EV-100

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FLOWSERVE CORPORATION
FLOW CONTROL DIVISION
Edward Valves
1900 South Saunders Street
Raleigh, NC 27603 USA

Toll- Free Telephone Service
(U. S. and Canada)
Day: 1-800-225-6989

After Hours Customer Service
1-800-543-3927

US Sales Offices
Phone: 919-832-0525
Facsimile: 919-831-3369
Facsimile: 919-831-3376

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