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ENERGY OPTIMISATION AND CONTROLLABILITY IN COMPLEX DISTILLATION COLUMNS

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CHAPTER 8. CONTROLLABILITY OF DIFFERENT DISTILLATION ARRANGEMENTS

8.1 Abstract

In this chapter, the controllability of different distillation arrangements for the separation of ternary mixtures is compared. Specifically, the trains of columns, the columns with side sections, and the DWC are considered. The influence of the number of trays on the relative controllability of the different arrangements is analysed. In order to compare the best controllability that every arrangement can give, the preferred control structures are chosen. Also, for the DWC, operating conditions that favour controllability are taken into account.

8.2 Introduction

In chapters two and three, different distillation arrangements for the separation of multicomponent mixtures were compared. Comparisons were mainly based on thermodynamic properties and only steady state was considered. The main objective was to find out which distillation arrangements are economically and energetically more favourable. Conclusions indicated that the DWC and the Petlyuk Column are very attractive in terms of energy consumption. On the other hand, in chapters four to seven, the control of the DWC was studied. It was seen that the DWC, which is very attractive in terms of energy consumption, is also controllable. In this chapter, the controllability of the DWC is compared to the controllability of other distillation arrangements. The main objective is to know if the DWC is still attractive when controllability is taken into account.

In section 3.5, it was seen that energy savings of one distillation arrangement relative to the others depend greatly on the number of trays of the arrangements. In chapter seven, it was seen that the DWC controllability depends on the number of trays of the arrangement. In this chapter, different comparisons are done for arrangements with different number of trays. In section 8.3, all the compared arrangements are based on *RR/MRR*=2. In section 8.4, all the compared arrangements are based on *RR/MRR*=1.23. In sections 8.5 and 8.6, arrangements with the same number of total trays are compared. In 8.5, all the arrangements have 46 trays and in section 8.6, all the arrangements have 58 trays.

In the literature, few works have addressed the control of complex distillation arrangements for the separation of multicomponent mixtures. Doukas et al. (1978 b) studied the control of a sidestream column. Four product compositions were controlled. Selection of the manipulated variables and tuning of PI controllers were discussed and simulation results were shown. To control the composition of the intermediate product, the location of the sidesteram tray was proposed. The control scheme was found to be successful facing several disturbances.

The same authors studied the control of a prefractionator system (Doukas et al., 1981). For the control of four product compositions, two different control structures were analysed. One of them had the sidestrean location as manipulated variable. The other had the prefractionator distillate rate as manipulated variable. Both schemes gave stable and effective control of the system for moderate disturbances.

Alatiqi et al. (1986) were the first to compare the controllability of two different distillation arrangements for the separation of a ternary mixture. The considered arrangements were the direct train of columns and the column with side stripper. Controllability was analysed through the *MRI* and other frequency dependent indexes. They concluded that the recycle and coupling nature of the column with side stripper contributed positively to disturbance attenuation.

The only authors that included the DWC in a comparison between controllability of different distillation arrangements were Hernandez et al., (1999). They compared the controllability of the DWC with that of the column with side stripper and that of the column with side rectifier. *MRI* and *CN* controllability indexes were used to quantify the comparisons. They found that the DWC was the most difficult to control. They study, however, did not analyse all the potential given by the DWC complexity.

In this chapter, a comparison similar to that of Hernandez et al., (1999) is done. However, several designs and control structures for composition and inventory control are considered. Also several DWC operating conditions are considered. Besides, the direct and the indirect trains of columns, as well as the columns with side sections and the DWC, are included in the comparison.

8.3 Comparison I: designs based on *RR/MRR*=2

A distillation problem is selected for the comparison study in this chapter. It consists in the separation described in 4.11 of an equimolar mixture with α=(4.65:2.15:1) into 0.99 pure products. As was considered in chapters four to seven, the composition control objective is the control of A, B, and C products purity. Controllability associated to the composition control loops is analysed. As was seen in 2.4.1, the simple column with sidestream is not able to solve the considered separation. This arrangement is not included in the comparative analysis.

For all the arrangements, the nominal operation is chosen the operation with minimum boilup, or sum of boilups in the arrangements with more than one reboiler. All extra operational DOF (DOF remaining after composition specifications) have been used for the operation optimisation. Therefore, for the trains of columns and the columns with side sections, one operation DOF is used for the operation optimisation and for the DWC, two operation DOF are used for the operation optimisation (see DOF analysis in chapter two).

The distillate and bottoms flowrates (external flows) are the manipulated variables for inventory control structures considered in sections 8.3 to 8.6.

In this section, the design of each of the arrangements is based on RR/MRR = 2. Specifically, the DWC, designed following the method explained in 2.6.2, has NT=46, NP=13, NM=33, NS=17, NCB=8, NCD=26 and NF=7. The designs of the direct and indirect trains of columns have been determined as explained in section 2.4.2. Location of the feed trays is optimised. The design of the direct train consists in NTI=18, $NTII$=19, NFI=9, and $NFII$=10 (see Figure 2.4). The design of the indirect train consists in NTI=18, $NTII$=19, NFI=10, and $NFII$=9 (see Figure 2.5). Finally, the designs of the column with side rectifier and the column with side stripper are derived from the designs of the indirect and the direct trains of columns as explained in section 2.4.3. The design of the column with side rectifier consists in NM=26, NR=11, NF=18, and NS=8 (see Figure 2.10). The design of the column with side stripper consists in NM=27, $NSTRIP$=10, NF=9, and NS=19 (see Figure 2.11).

The direct and the indirect trains of columns have *LI, VI, LII,* and *VII* as possible manipulated variables. The column with side rectifier has *LM, VM, VAP*, and *LR* as possible manipulated variables and the column with side stripper has *LM, VM, LIQ*, and *VS* as possible manipulated variables. According to *MRI* and *CN* (see section 4.7.3), the preferred control structures are determined. In Table 8.1, the energy requirement in terms of boilup and the preferred control structures for the different arrangements are shown. In Figures 8.1 to 8.6, the *MRI* and the *CN* for all possible composition control structures of all the arrangements are shown. Profiles corresponding to the preferred control structures are indicated.

In Figures 8.1 and 8.2, it can be seen that the preferred structure for the indirect train of columns (*LI LII VII*) has larger *MRI* and lower *CN* than the preferred structure for the direct train of columns (*LI LII VII*). Therefore, the direct train of columns, which is more energy consuming, has also a worse controllability. A similar thing can be observed comparing the column with side rectifier and the column with side stripper. In Figures 8.3 and 8.4, it can be seen that the preferred structures for the column with side stripper (*LM VM VS* / *LM VM LIQ*) have larger *MRI* and lower *CN* than the preferred structures for the column with side rectifier (*LM VM LR* / *LM VM VAP*). The column with side rectifier is more energy consuming and it also has a worse controllability. Therefore, for the studied separation, the indirect train of columns and the column with side stripper are superior to the direct train of columns and the column with side rectifier in terms of energy and in terms of controllability.

Table 8.1: Energy consumption and preferred composition control structures for different distillation arrangements

	Boilup (kmol/min)	Best control structure
Direct train (37 trays)	3.58	*LI LII VII*
Column with side rectifier (37 trays)	3.43	*LM VM LR / LM VM VAP*
Indirect train (37 trays)	3.28	*LI LII VII*
Column with side stripper (37 trays)	3.12	*LM VM VS / LM VM LIQ*
DWC (46 trays)	2.66	*L S V*
DWC non-optimal operation (46 trays)	2.89	*L SPLITD S*

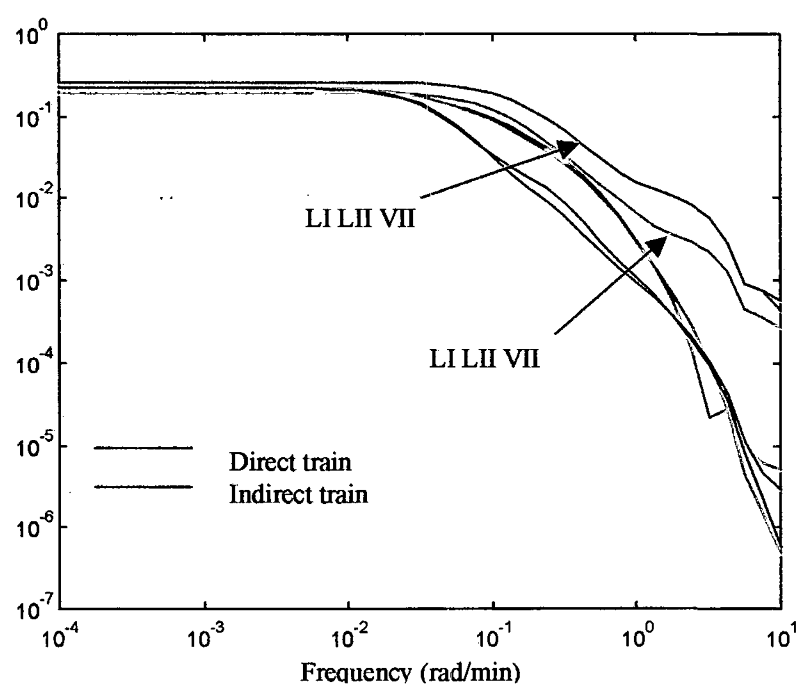

Figure 8.1: *MRI* of all the composition control structures

In Figures 8.5 and 8.6, *MRI* and *CN* of the different control structures of the DWC are plotted. At frequencies lower than 0.1 rad/min, the *L S V* control structure is clearly the one associated to the best controllability. Since the bandwidth frequency is expected to be smaller than 0.1 rad/min (see section 7.3.1), *L S V* is the expected preferred control structure.

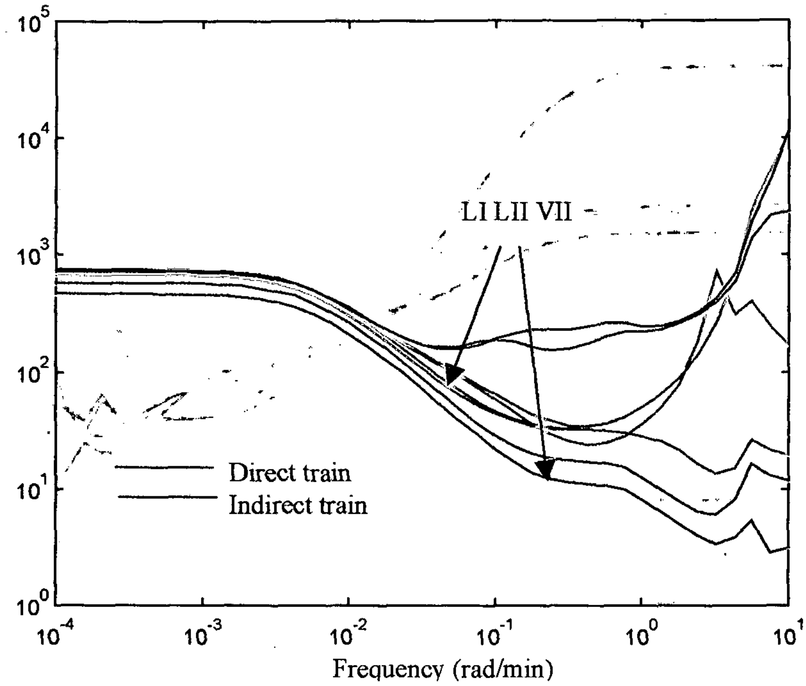

Figure 8.2: *CN* of all the composition control structures

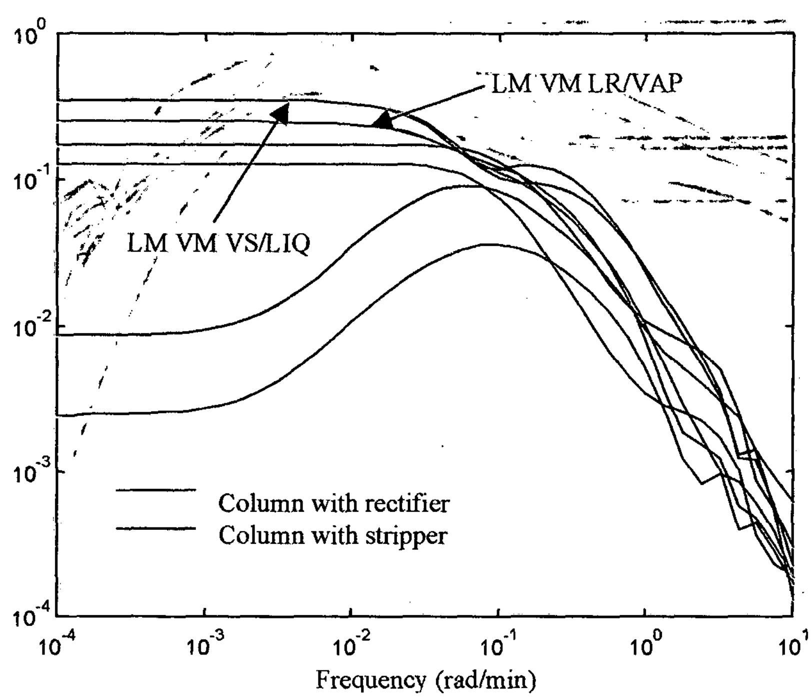

Figure 8.3: *MRI* of all the composition control structures

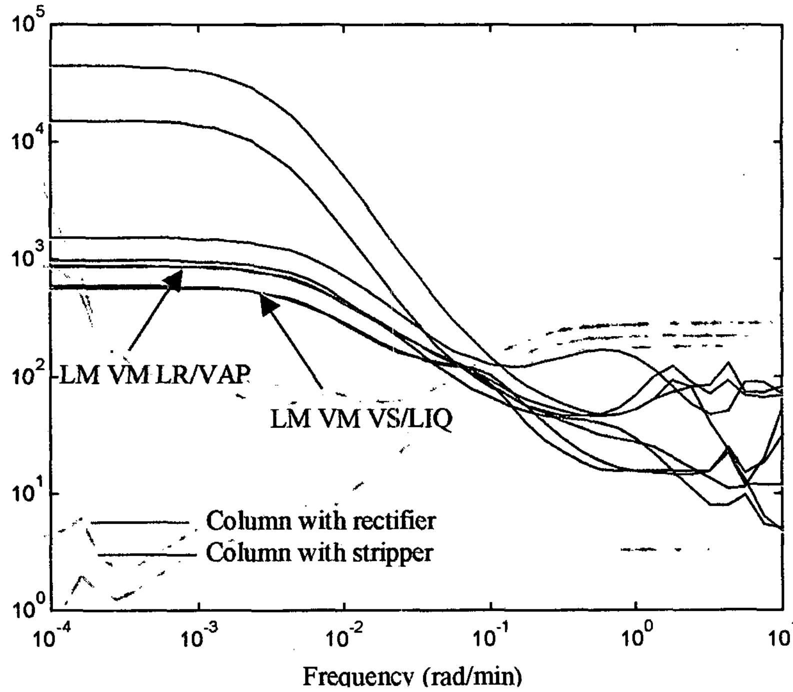

Figure 8.4: *CN* of all the composition control structures

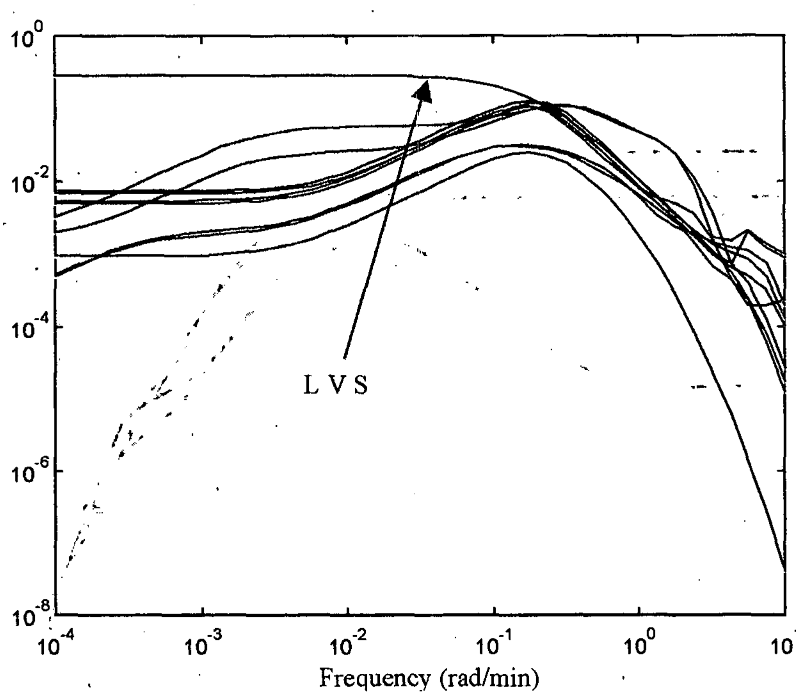

Figure 8.5: *MRI* of all the composition control structures

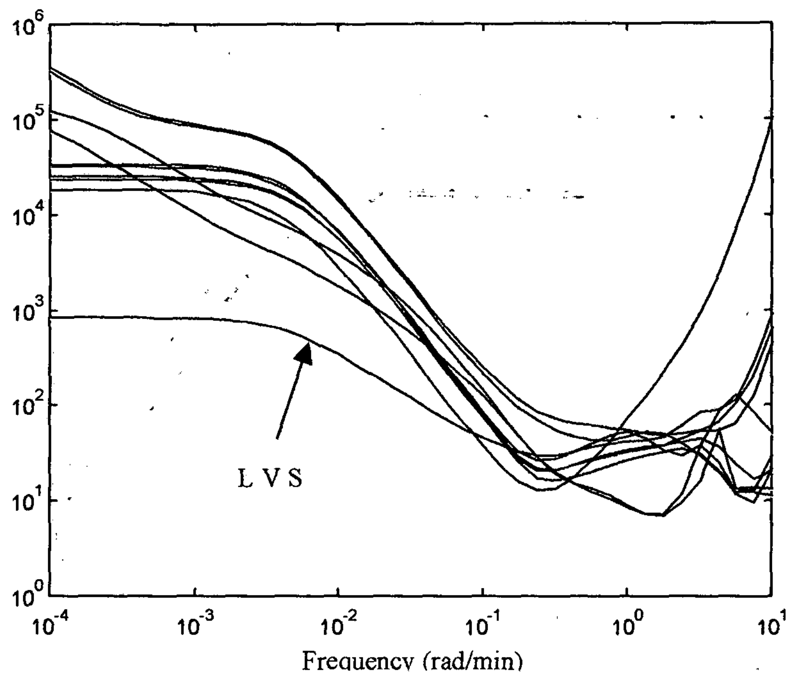

Figure 8.6: *CN* of all the composition control structures

In Figures 8.7 and 8.8, the *MRI* and the *CN* for the best control structures of the indirect train, the column with side stripper, and the DWC are plotted together. The indirect train of columns has the smallest *CN* (good thing), but it has also the smallest *MRI* (bad thing). The column with side stripper has the worst controllability in a range of frequencies around 0.1 rad/min. The DWC has the largest *CN* of all the arrangements. In general, results indicate that the indirect train of columns has the best controllability and the DWC has the worst controllability.

RGA has been used to select appropriate pairings. The pairing showing lower interaction for the indirect train is *LII VII LI*, and for the column with side stripper, it is *LM VS VM*. For the DWC, the best pairing is *L S V*. In Figure 8.9, the ***RGA*** diagonal elements of the three arrangements can be seen. The column with side stripper has the larger ***RGA*** values. However, the behaviour of all the arrangements is similar. It is interesting to notice that the indirect train of columns has a variable absolutely decoupled of the rest (***RGA*** diagonal element equal to one).

In chapters four and seven, it was seen that working out of the optimal operation, the controllability of the DWC improved. It will be thus interesting to compare the controllability of the indirect sequence and the column with side stripper with that of a DWC operated at non-optimal conditions. The chosen non-optimal operation is found fixing *SPLITD* at 0.650 (the optimal value of *SPLITD* is 0.634). The increase in boilup due to the change of operation is of 8.6%. In Table 8.1, the boilup and preferred control structure for the non-optimal operated DWC are indicated in the last row. In Figures 8.7, 8.8, and 8.9, it corresponds to the "-.-.-" green line. Its best control structure is *L S SPLITD*, and ***RGA*** indicates that the best pairing is *L SPLITD S*.

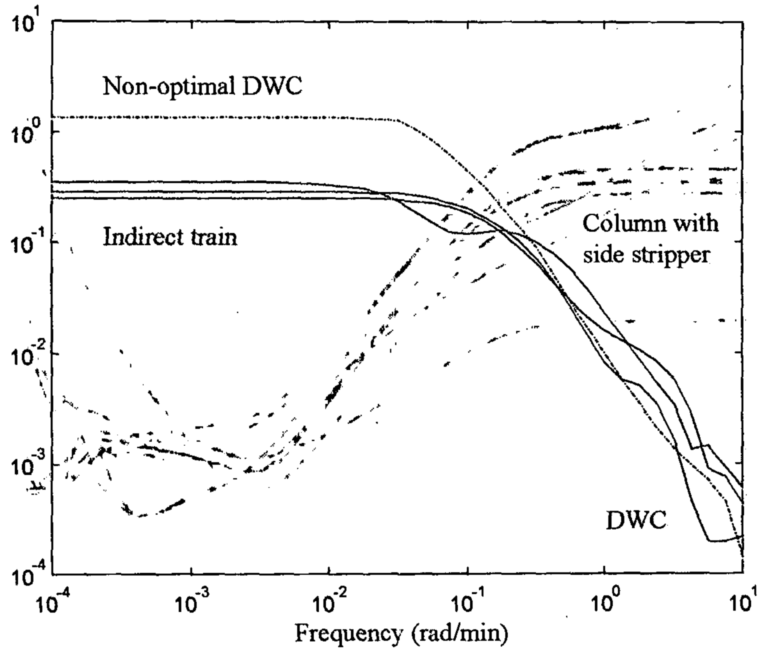

Figure 8.7: *MRI* of the best control structures for the indirect train, the column with side stripper, and the DWC

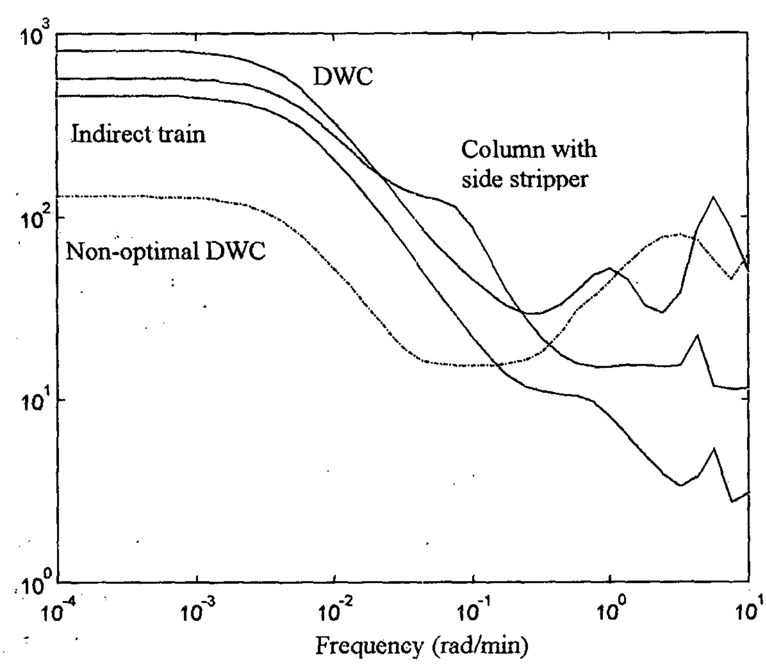

Figure 8.8: CN of the best control structures for the indirect train, the column with side stripper, and the DWC

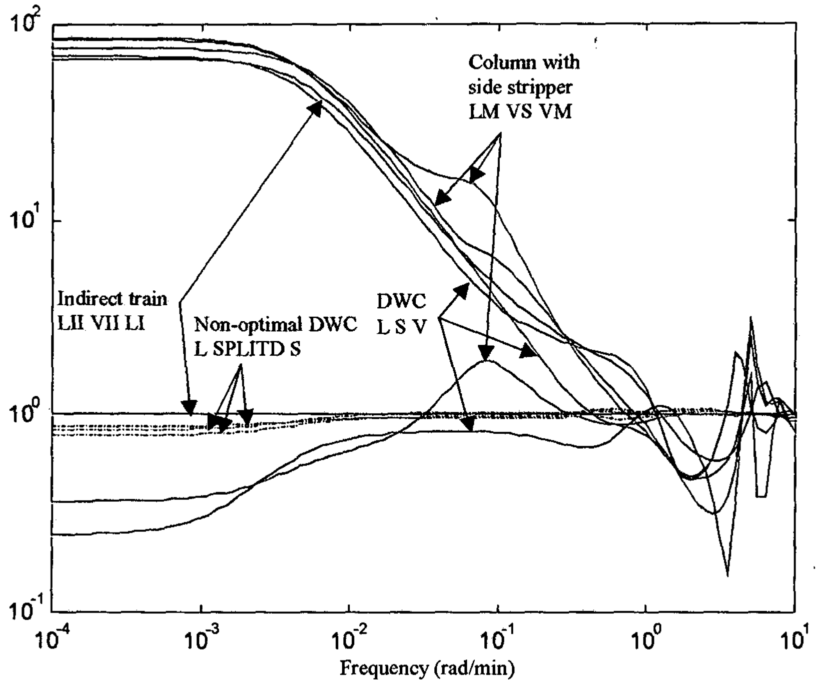

Figure 8.9: *RGA* diagonal elements of the best paired control structures

Evidently, the energy consumption of the DWC at non-optimal operation has increased compared to the energy consumption at optimal operation. However, as can be seen in Table 8.1, it is still lower than the energy consumption of the other distillation arrangements. On the other hand, the controllability is considerably better: higher *MRI*, lower *CN* and more diagonal ***RGA***. This result is very important because it indicates that the DWC, operated at some specific nominal conditions, has the lowest energy consumption and the best controllability of the considered distillation arrangements. The other distillation arrangements could also be operated at non-optimal conditions, but only small changes are expected because, with products of purity 0.99, the trains of columns and the columns with side sections only have a small operability range.

8.4 Comparison II: designs with *RR/MRR*=1.23

In chapter seven, it was seen how the controllability of the DWC may be improved increasing the number of trays in the column from 46 to 58. In this section, the same arrangements compared in the previous section are compared, but longer columns are considered. The designs are determined as explained the previous section but this time, they are based on *RR/MRR*=1.23. The resulting indirect train of columns has *NTI*=26, *NTII*=27, *NFI*=12, and *NFII*=15. The column with side stripper has *NM*=38, *NSTRIP*=15, *NF*=12, and *NS*=26. Finally, the DWC has *NT*=58, *NP*=18, *NM*=40, *NS*=21, *NCB*=10, *NCD*=31, and *NF*=9.

The boilup rate and the preferred control structures for the different arrangements are shown in Table 8.2. Energy savings of the DWC are similar to those found in 8.3, and the preferred composition control structures are the same.

Table 8.2: Energy consumption and preferred composition control structures for different distillation arrangements

	Boilup (kmol/min)	Best control structure
Indirect train (53 trays)	2.10	*LI LII VII*
Column with side stripper (53 trays)	1.96	*LM VM VS*
DWC (58 trays)	1.67	*L S V*

In Figures 8.10 and 8.11, the *MRI* and the *CN* of the preferred control structures for the three distillation arrangements are shown. Comparing Figures 8.7 and 8.8 with Figures 8.10 and 8.11, it can be seen that the controllability of all the arrangements improves with longer columns in a way that the controllability order does not change. This way, again, the indirect train of columns has the smallest *CN* and the smallest *MRI*, the column with side stripper has the worst controllability in a range of frequencies around 0.1 rad/min, and the DWC has the largest *CN* of all the arrangements. Therefore, increasing the number of trays of the arrangements does not favour the DWC controllability more than the controllability of the other arrangements.

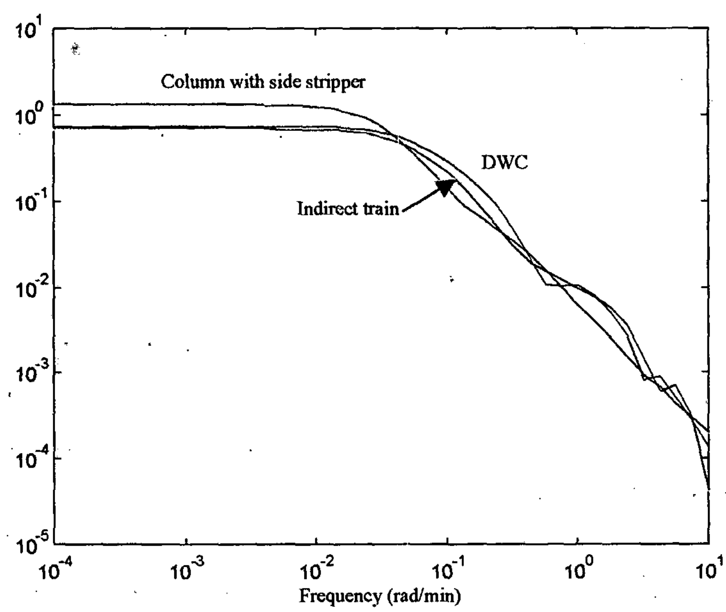

Figure 8.10: *MRI* of the best control structures for arrangements with *RR/MRR*=1.23

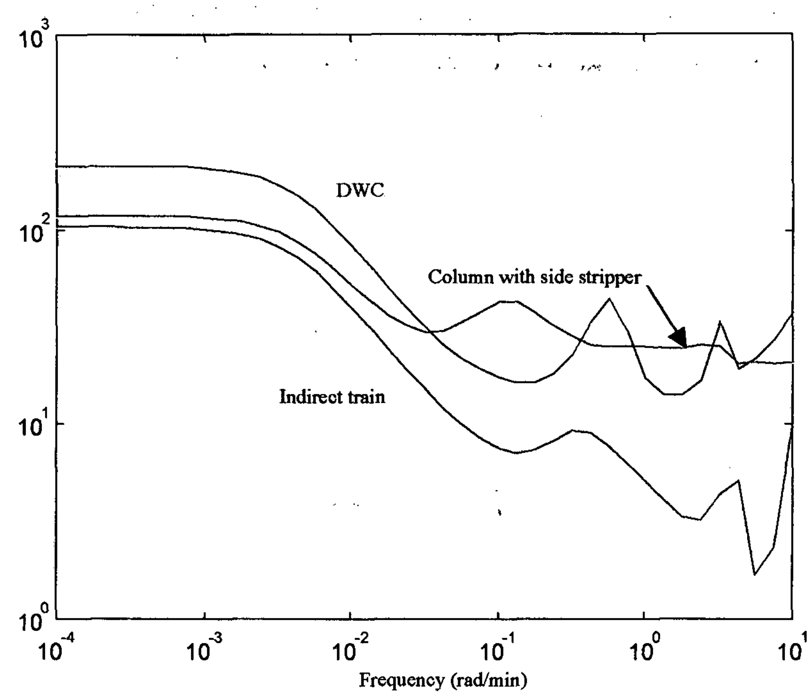

Figure 8.11: *CN* of the best control structures for arrangements with *RR/MRR*=1.23

To have an idea of the bandwidth frequencies of the different arrangements, and to make a primary stability analysis, a tuning of K_c=0.2, τ_c=80 min has been applied to every loop of the three compared arrangements. Bandwidth frequencies corresponding to this tuning and controllability indexes at these bandwidths are shown in Table 8.3. At the bandwidth frequency, the arrangement with the best controllability indexes is the indirect train of columns, followed by the DWC. The arrangement with the worst controllability indexes is the column with side stripper. *MRI* and *CN* of the column with side stripper are better than *MRI* and *CN* of the DWC for a long range of frequencies. However, around the bandwidth frequency, they are worse. This is an important result, which indicates that at optimal operation, the DWC may be better than the column with side stripper in terms of energy and also in terms of controllability.

Table 8.3: bandwidth frequency and controllability indexes for the different arrangements

	Bandwidth frequency	*MRI* at bandwidth	*CN* at bandwidth
Indirect train (53 trays)	0.05 rad/min	0.41	10
Col. With side stripper (53 trays)	0.07 rad/min	0.22	36
DWC (58 trays)	0.07 rad/min	0.37	19

In Figures 8.12 and 8.13, the maximum singular values of the complementary sensitivity function ***T*** and the maximum singular values of ***wi*Ti*** are shown. In section 4.9.1, the use of these plots as tools for the stability analysis was introduced. The same input uncertainty considered in section 4.9.1 are considered in this chapter (wi=0.2*(5s+1)/(0.5s+1)). In Figure 8.12, it is seen that the DWC has the smallest stability margins (the larger peak), but the column with side stripper has also a large peak. In Figure 8.13, it can be seen that none of the arrangements have a peak larger than 1, what indicates that all they have robust stability for full-block *wi* uncertainty at the input.

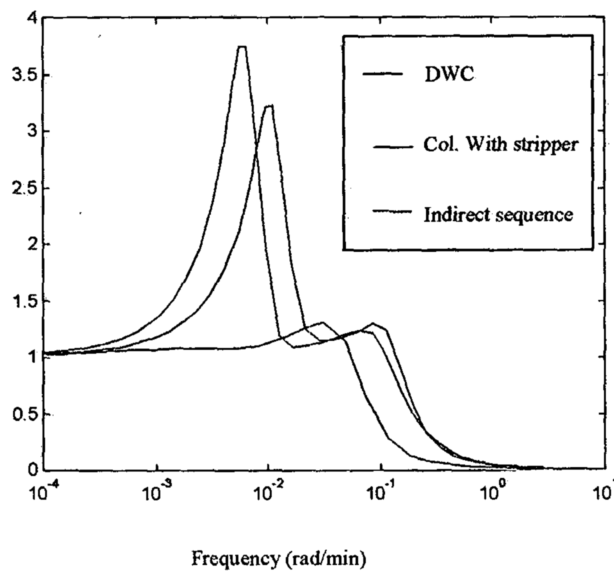

Figure 8.12: max(σ (***T***))

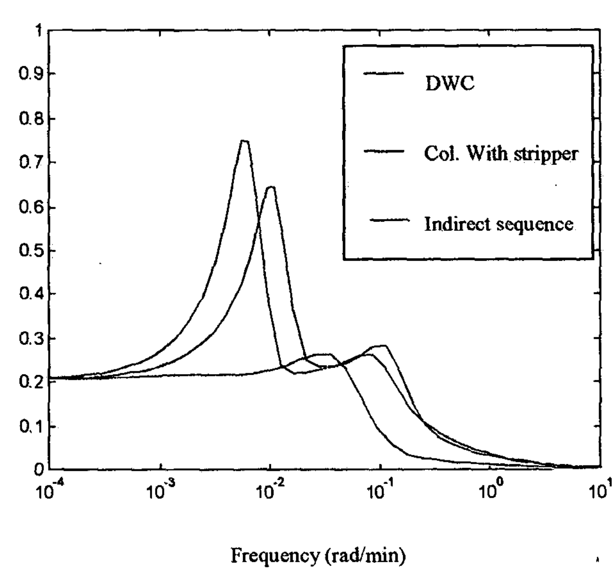

Figure 8.13: max(σ (wi*T_I))

Although a better analysis is required to test all possible tunings, this first analysis shows that the indirect train of columns has better controllability and stability than the column with side stripper and the DWC.

8.5 Comparison III: designs with 46 trays

In this section and the following one, controllability of the different arrangements with the same number of trays is compared. In this section, all the arrangements have 46 trays. With the total number of trays fixed, optimal designs in terms of boilup are selected. The DWC optimal design with 46 trays was indicated in section 8.3. For the indirect train, the optimum design is *NTI*=23, *NTII*=23, *NFI*=11, and *NFII*=12. For the column with side stripper, the optimum design is *NM*=34, *NSTRIP*=12, *NF*=11, and *NS*=23.

The energy requirement in terms of boilup rate and the preferred control structures of the different arrangements are shown in Table 8.4. As can be observed, the preferred control structures have not changed with the column length. As was seen in chapter three, the DWC with few trays is less efficient than the other arrangements.

Table 8.4: Energy consumption and preferred composition control structures for different distillation arrangements

	Boilup (kmol/min)	Best control structure
Indirect train (46 trays)	2.36	*LI LII VII*
Column with side stripper (46 trays)	2.18	*LM VM VS*
DWC (46 trays)	2.66	*L S V*

In Figures 8.14 and 8.15, *MRI* and *CN* of the best control structures of the three arrangements can be seen. It is interesting to compare Figures 8.14 and 8.15 with Figures 8.7 and 8.8. *MRI* of the column with side stripper is still lower than *MRI* of the DWC for some frequency values. However, the *CN* of the DWC is larger than the *CN* of the column with side stripper for all frequencies. The controllability of the DWC is worse than the controllability of the indirect train of columns and the controllability of the column with side stripper and differences are larger comparing columns with the same number of trays. Therefore, comparing these three arrangements with the same number of trays, the DWC is not energetically favourable and besides, the controllability difference has increased. It can be concluded that the DWC, compared to other arrangements with the same number of trays, is not preferred in terms of energy, and neither in terms of controllability.

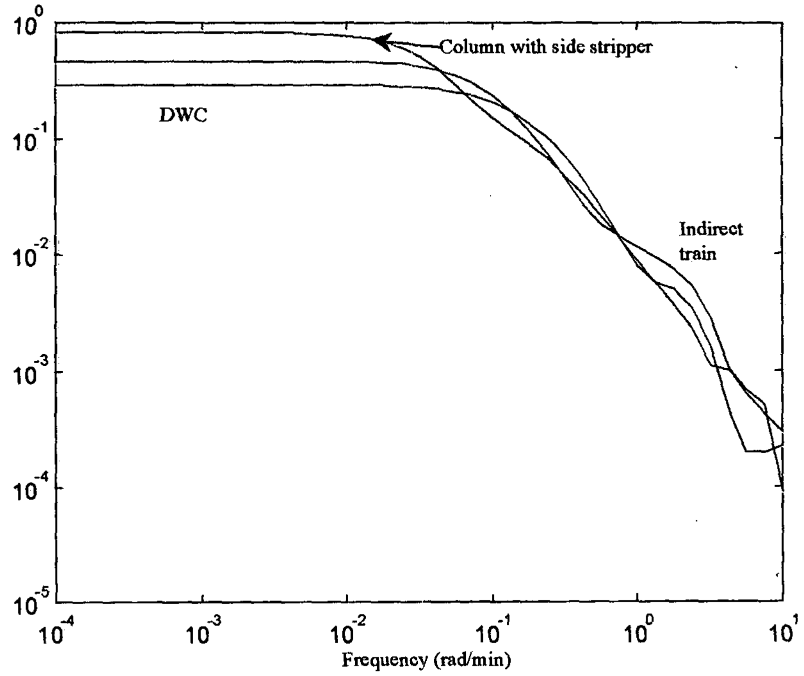

Figure 8.14: *MRI* of the best control structures for the arrangements with 46 trays

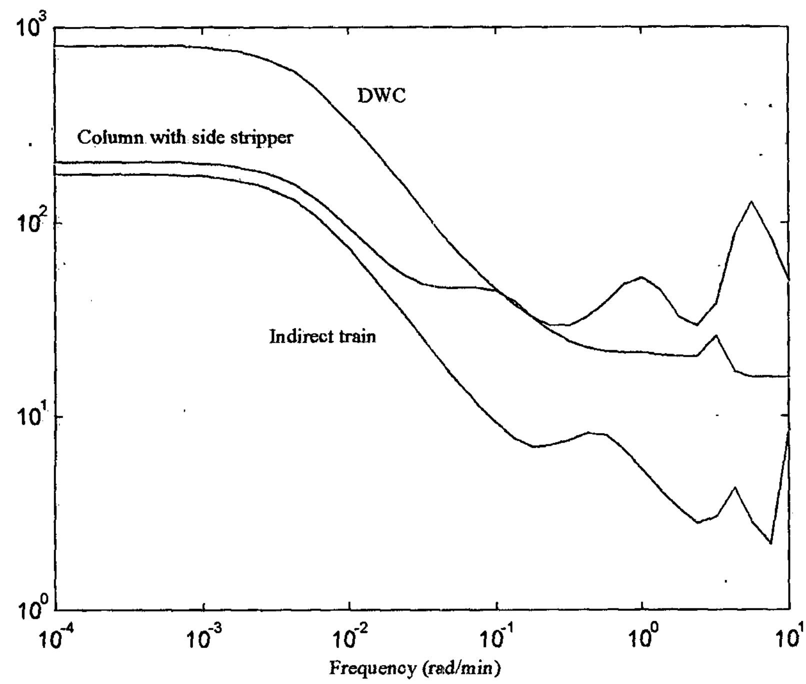

Figure 8.15: *CN* of the best control structures for the arrangements with 46 trays

8.6 Comparison IV: designs with 58 trays

In this section, all the compared arrangements have designs with 58 trays. With the total number of trays fixed, the designs for which the boilup is minimal are selected. The DWC optimal design with 58 trays was indicated in section 8.4. The indirect train of columns has *NTI*=29, *NTII*=29, *NFI*=13, and *NFII*=16. The column with side stripper has *NM*=42, *NSTRIP*=16, *NF*=13, and *NS*=29.

The energy requirement in terms of boilup rate and the best control structures for the different arrangements are shown in Table 8.5. The preferred control structures have not changed with the design changes.

Table 8.5: Energy consumption and preferred composition control structures for different distillation arrangements

	Boilup (kmol/min)	Best control structure
Indirect train (58 trays)	2.00	*LI LII VII*
Column with side stripper (58 trays)	1.86	*LM VM VS*
DWC (58 trays)	1.67	*L S V*

In Figures 8.16 and 8.17, the *MRI* and *CN* plots are shown for the best control structures of the indirect train of columns, the column with side stripper, and the DWC. Contrarily at what happened for arrangements with 46 trays, having all the arrangements 58 trays, the DWC is energetically preferred. However, the controllability is equally the worst one.

Comparing results in sections 8.3 to 8.6, it can be concluded that for more compatible controllability, the DWC needs to be designed with more trays than the other arrangements, what happens when all designs are based on the same *RR/MRR* (sections 8.3 and 8.4). In chapter seven, it was seen that also for reduced energy consumption, the DWC needs to be designed with more trays than the other arrangements.

In sections 8.3 to 8.6, it has been seen that for the studied separation and inventory control made by the external streams, at optimal operation, the controllability of the DWC is worse than the controllability of the indirect train of columns. Comparing the controllability of the DWC with that of the column with side stripper, results are not so clear. Controllability indexes indicate a superiority of the column with side stripper for a long range of frequencies. However, at frequencies close to the bandwidth, the DWC has better controllability indexes. In the next section, other inventory control structures are compared.

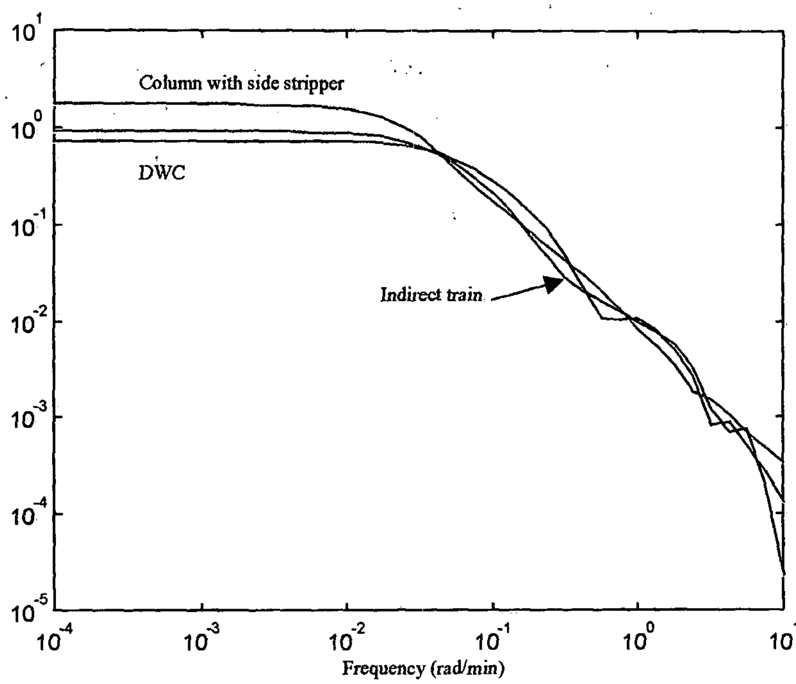

Figure 8.16: *MRI* of the best control structures for the arrangements with 58 trays

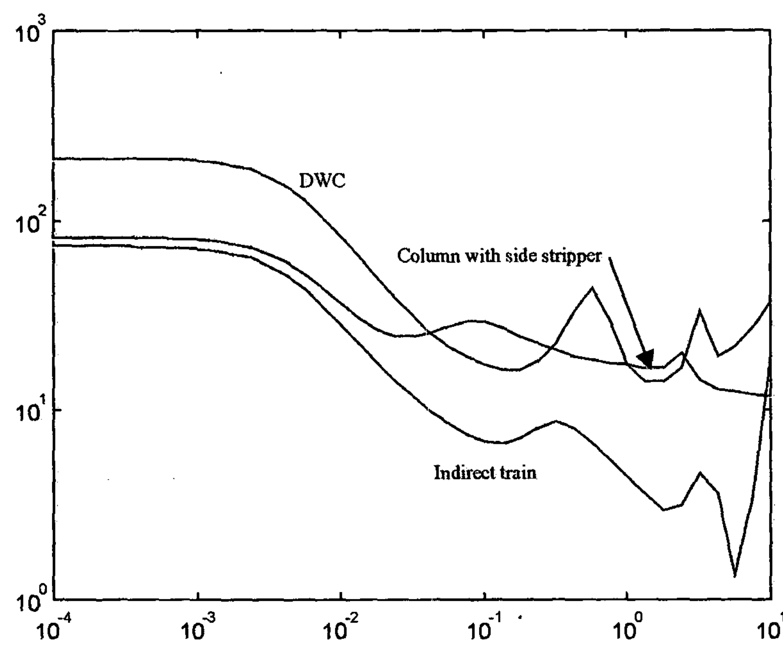

Figure 8.17: *CN* of the best control structures for the arrangements with 58 trays

8.7 Inventory control structures with internal flows

In chapters four and seven, it was seen that the controllability of the DWC for the inventory control structure consisting in the manipulation of L and V has good properties. Comparing the controllability of the DWC with "LV" inventory control with the controllability of the other distillation arrangements with inventory control made by distillate and bottoms flowrates (external variables), the controllability of the DWC is the best, as can be seen in Figures 8.18 and 8.19. The compared columns are the DWC with 58 trays, the indirect sequence with 53 trays, and the column with side stripper with 53 trays.

However, the controllability indexes of the indirect train of columns and the column with side stripper may also be improved changing of inventory control structure. In the DWC, two control loops are necessary to stabilise the arrangement. In the column with side stripper, three control loops are necessary to stabilise the arrangement. In the indirect train of columns, four control loops are necessary to stabilise the arrangement. Therefore, the number of inventory control possibilities in the column with side rectifier and in the indirect train of columns is very large.

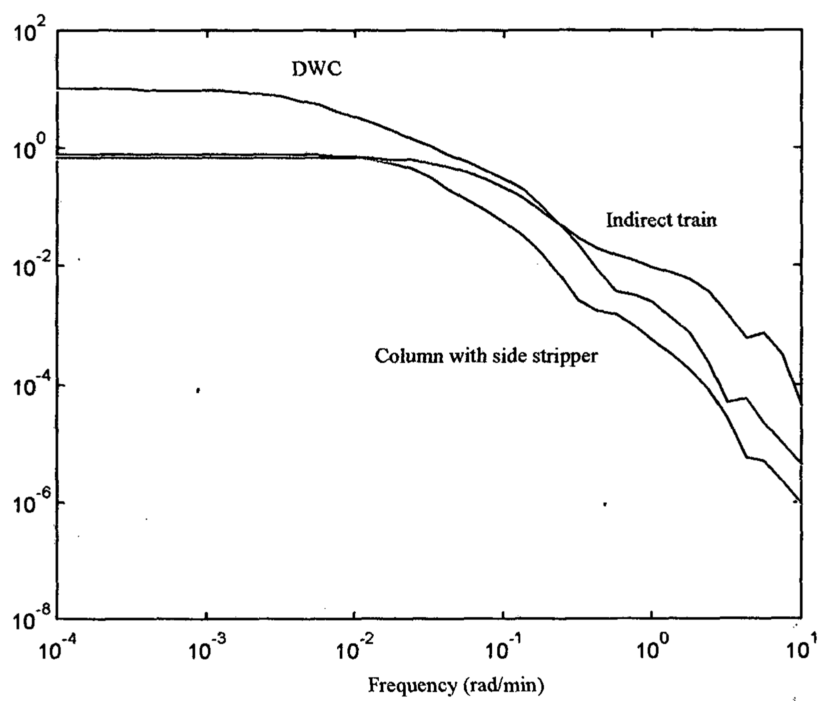

Figure 8.18: *MRI* for DWC with "LV" inventory control structure

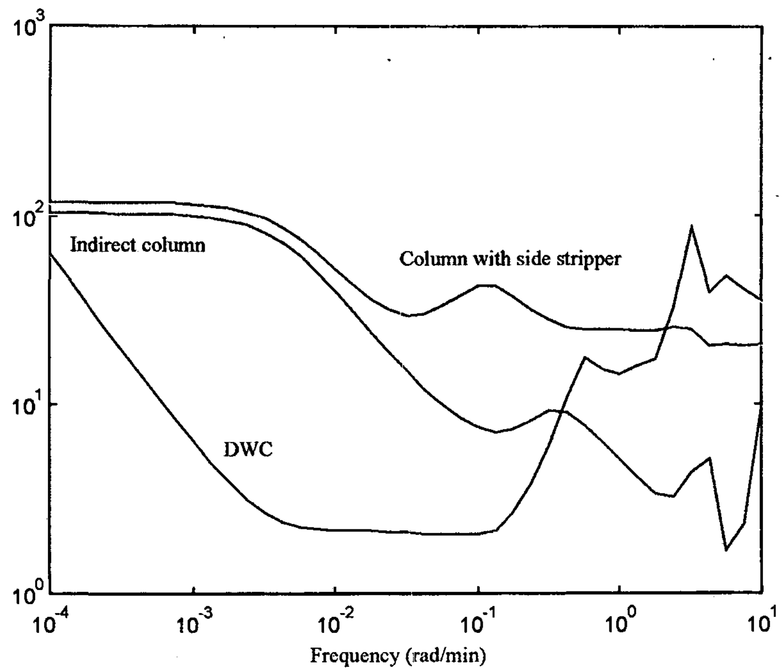

Figure 8.19: *CN* for DWC with "LV" inventory control structure

The nominal operation (optimal) of the indirect train with 53 trays has *LI/DI*=1.1, *LII/DII*=3.1, *VI/BI*=4.2 and *VII/BII*=2.2. The only reflux ratio larger than 4 is *VI/BI*. To use the large flowrate to control the liquid level of a tank when reflux ratio is larger than 4 (see section 4.6), the liquid level in the bottom of the first column should not be controlled by *BI*. Controllability of the indirect sequence with four different inventory control structures is compared. In Table 8.6, controllability indexes of the best structures are indicated. The inventory control structure in the first row is the one studied in sections 8.3 to 8.6. The inventory control structure in the second row has the internal flow as manipulated variable only in the column end where reflux ratio is larger than 4. For the inventory control structure in the last row, all manipulated variables are internal flows.

The nominal operation (optimal) of the column with side stripper has *LM/D* and *VM/BM* larger than 4. On the contrary, *VS/BS* is smaller than 4. In Table 8.7, the controllability indexes of the preferred structures for three different inventory control structures are shown. The inventory control in the first row is the one studied in sections 8.3 to 8.6. The one in the second row has the internal flows as manipulated variable only in the column ends where reflux ratios are larger than 4. For the inventory control structure in the last row, all manipulated variables are internal flows.

The control structure with higher *MRI* and lower *CN* for the indirect train of columns is inventory control *DI VI LII VII* and composition control *BI DII BII*. The structure with higher *MRI* and lower *CN* for the column with side stripper is inventory control *LM VM BS* and composition control *D BM VS*. In Figures 8.20 and 8.21, *MRI* and *CN* of the DWC, the indirect train of columns and the column with side stripper for the best control structures are plotted in a wide frequency range. Interestingly, it can be seen that the DWC has the lower *CN* for a large range of frequency. Contrarily at what happens for inventory control made by the external flows, for inventory control made by the internal flows, the indirect train of columns has the worst controllability indexes.

Table 8.6: Preferred structures for different inventory control structures for the indirect train

	Preferred composition control structure	*MRI* (w=0.0001 rad/min) / *CN* (w=0.0001 rad/min)	*MRI* (w=0.04 rad/min) / *CN* (w=0.04 rad/min)
DI BI DII BII	*LI LII VII*	*MRI* = 0.65	*MRI* = 0.47
		CN = 100.5	*CN* = 12.3
DI VI DII BII	*LI BI VII*	*MRI* = 0.83	*MRI* = 0.22
		CN = 41.5	*CN* = 13.7
DI VI LII VII	*BI DII BII*	*MRI* = 9.1	*MRI* = 0.74
		CN = 89.3	*CN* = 2.58
LI VI LII VII	*BI DII BII*	*MRI* = 7.97	*MRI* = 0.75
		CN = 91.9	*CN* = 1.9

Table 8.7: Preferred structures for different inventory control structures for the stripper

	Preferred structure	*MRI* (w=0.0001 rad/min) / *CN* (w=0.0001 rad/min)	*MRI* (w=0.04 rad/min) / *CN* (w=0.04 rad/min)
D BM BS	*LM VM VS*	*MRI* = 1.25	*MRI* = 0.54
		CN = 114.8	*CN* = 29.3
LM VM BS	*D BM VS*	*MRI* = 11.9	*MRI* = 0.94
		CN = 76.5	*CN* = 1.95
LM VM VS	*D BM BS*	*MRI* = 9.17	*MRI* = 0.68
		CN = 80.9	*CN* = 2.62

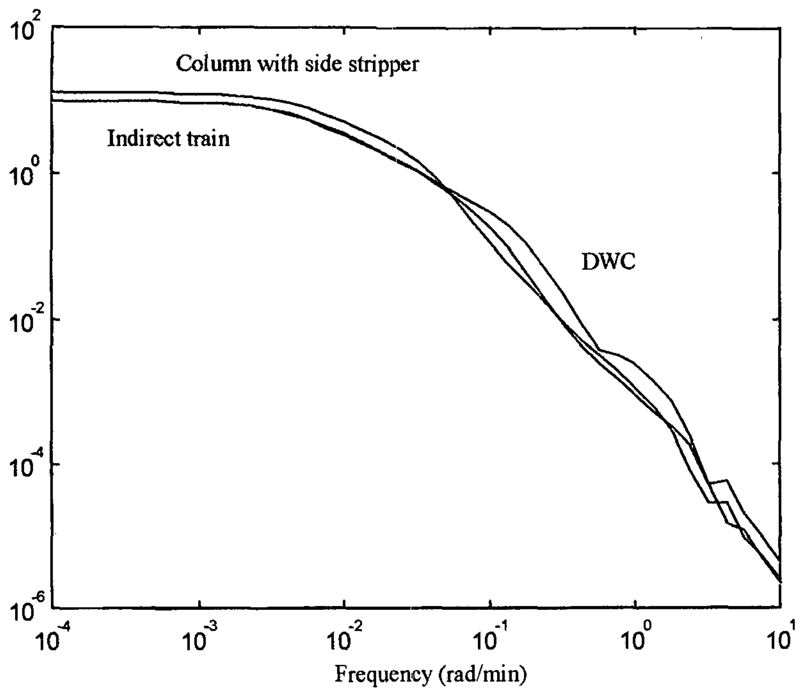

Figure 8.20: *MRI* for inventory control structures with internal flows

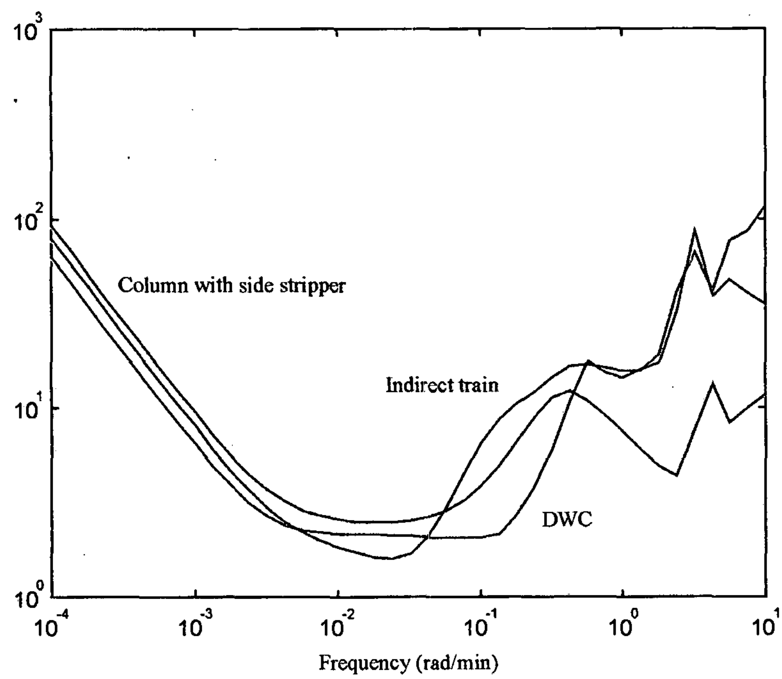

Figure 8.21: *CN* for inventory control structures with internal flows

8.8 Conclusions

Comparing for a case study the direct train of columns with the indirect train of columns, and the column with side rectifier with the column with side stripper, it is seen that the most energy efficient arrangements have the best controllability. Specifically, the indirect train has lower energy consumption and better controllability than the direct train, and the column with side stripper has lower energy consumption and better controllability than the column with side rectifier. However, when comparing different distillation arrangements, it is not found that lower energy consumption and better controllability go together.

In general, for stabilisation control made by the distillate and bottoms flowrates, the complexity of a distillation arrangement makes its controllability worse. Therefore, the controllability of the train of columns is better than the controllability of the column with side section, and this is better than the controllability of the DWC. However, some interesting exceptions have been found:

- At optimal operation, the controllability of the DWC is worse than the controllability of the indirect sequence. However, comparing the controllability of the DWC with that of the column with side stripper, results are not clear. Controllability indexes indicate a superiority of the column with side stripper for a long range of frequencies. However, for frequencies that could be close to the bandwidth, the DWC has better controllability indexes.
- At optimal operation, the DWC controllability is worse than that of the train of columns. However, operating the DWC at a non-optimal operation, its controllability is much better, and it is even better than the controllability of the other arrangements. This result is very important because indicates that the DWC, operated at some specific nominal conditions, has lower energy consumption and better controllability than the other distillation arrangements.

Considering the reflux flowrates and the boilups as manipulated variables for the stabilisation control, at optimal operation, the DWC *CN* is lower than the *CN* of the other arrangements.

Finally, comparing the controllability of different arrangements for different design conditions, it has been seen that the DWC controllability, compared to the controllability of the other arrangements, is better when the DWC design consists of more trays. It is also in this case that the DWC energy savings are higher. Therefore, the DWC needs long columns to be really attractive in terms of energy as well as in terms of controllability.