UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: JUNE 2019

COURSE AND CODE: PROCESS DYNAMICS & CONTROL ENCH4DC

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINER(S): DR K MOODLEY
PROF R RAWATLAL

INTERNAL MODERATOR(S): DR S MOODLEY

EXTERNAL MODERATOR: MR JC PILLAY

INSTRUCTIONS:

1. **ALL** questions should be attempted.
2. **Two answer books are provided. Label them Book A and Book B respectively. Answer Section A in Book A and Section B in Book B.**
3. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
4. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
5. Detach page 5 and hand in with answer booklet A and detach page 8 and hand in with answer booklet B.
7. This examination question paper, together with all associated diagrams **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

SECTION A

QUESTION 1

An evaporator with an overhead exit is shown below in Figure 1. The liquid level in the evaporator varies, hence the surface for heat transfer varies with liquid level. The temperature difference between the operational and feed conditions have a negligible effect on the heat capacity and density. The feed is a liquid.

a) Determine the dynamic mass balance and energy balance of the vessel. (7)

b) Combine the models appropriately and linearize the models (5)

State all assumptions.

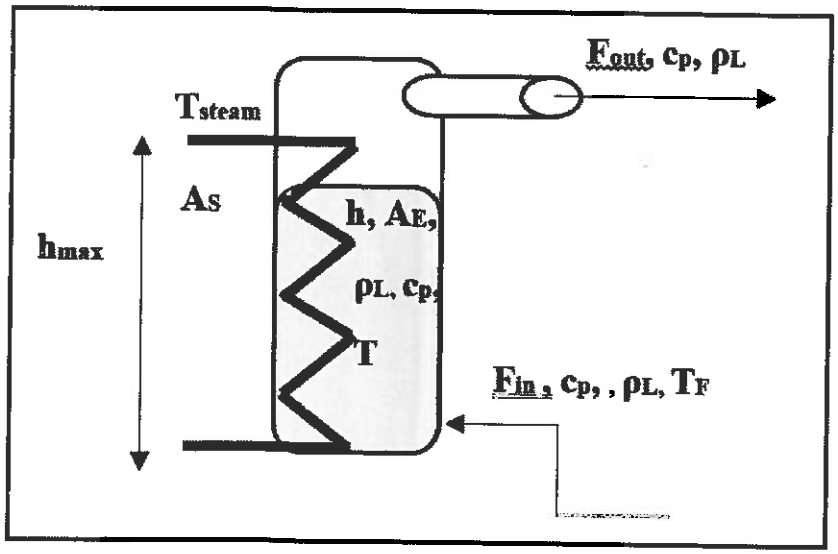


Figure 1. Evaporator with overhead exit

F_{in}-feed flow (kmol/s), T_F-feed temperature (K), c_p-heat capacity (kJ/(kmol.K)), ρ_L-liquid molar density in (kmol/m^3), h-liquid height (m), h_{max}-liquid height when coil is completely submerged in liquid (m), A_E-cross sectional area of evaporator vessel (m^2), T_{steam}-steam temperature into coil (K), U- overall heat transfer coefficient in reboiler (kJ/(m^2.K)), A_s-**maximum** surface area of coil (m^2), T-temperature (K), ΔH_{vap}–heat of vaporization in condenser (kJ/kmol), F_{out} outlet flow rate (kmol/s).

TOTAL /12/

QUESTION 2

By stepping up the fuel flow to a furnace by **2 $m^3.h^{-1}$**, the following response in the coil exit temperature is obtained as shown in Figure 2:

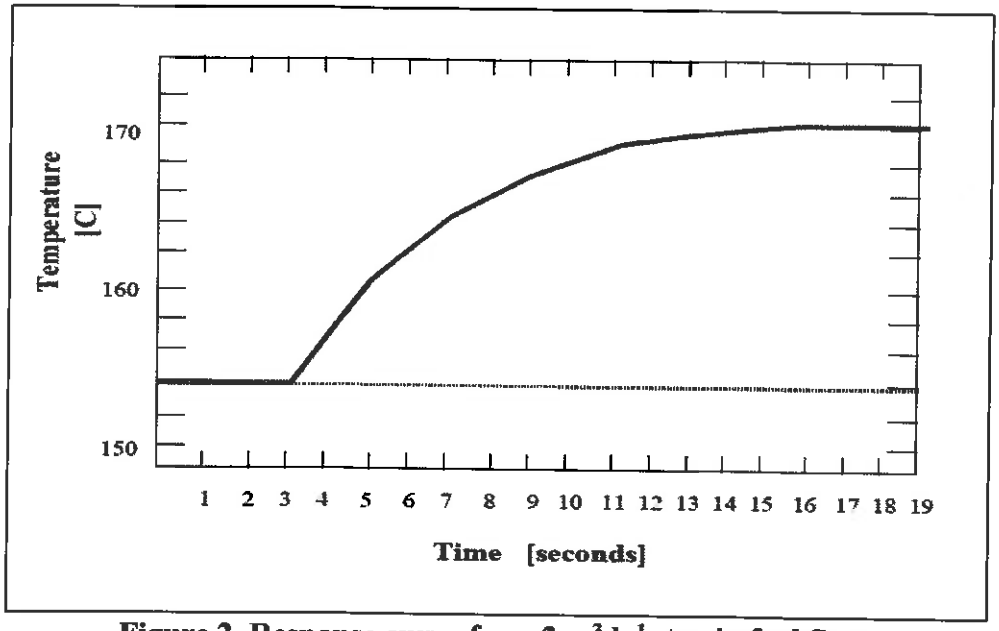


Figure 2. Response curve for a 2 $m^3.h^{-1}$ step in fuel flow.

Find the response of the coil exit temperature to the variation of the fuel flow shown in Figure 3.

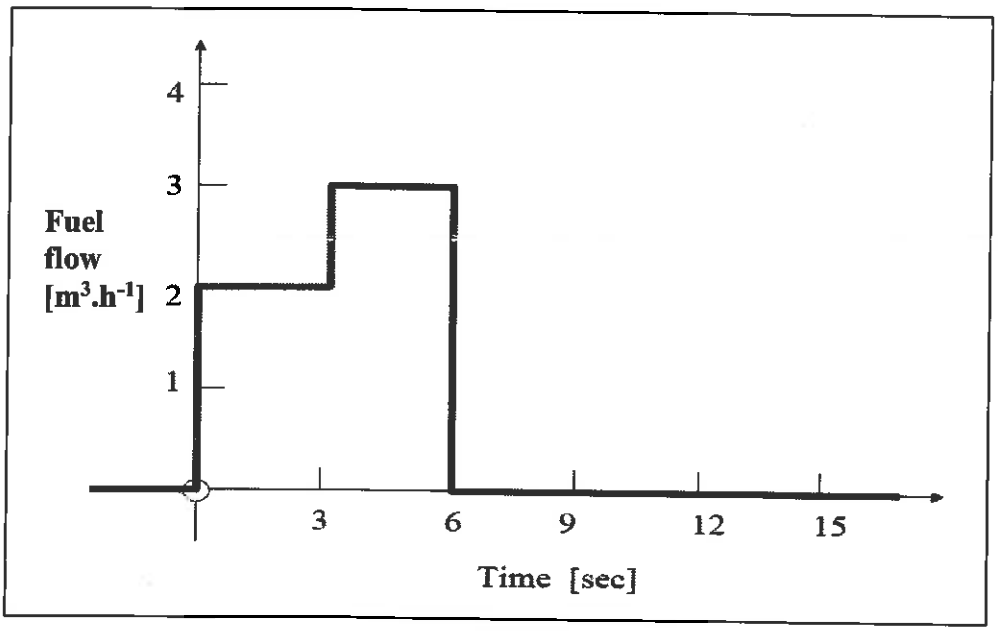


Figure 3. Variation in fuel flow.

TOTAL /8/

QUESTION 3

Streams F1 and F2 are being used to control the composition and temperature in stream F3 in the stirred vessel of Figure 4 below.

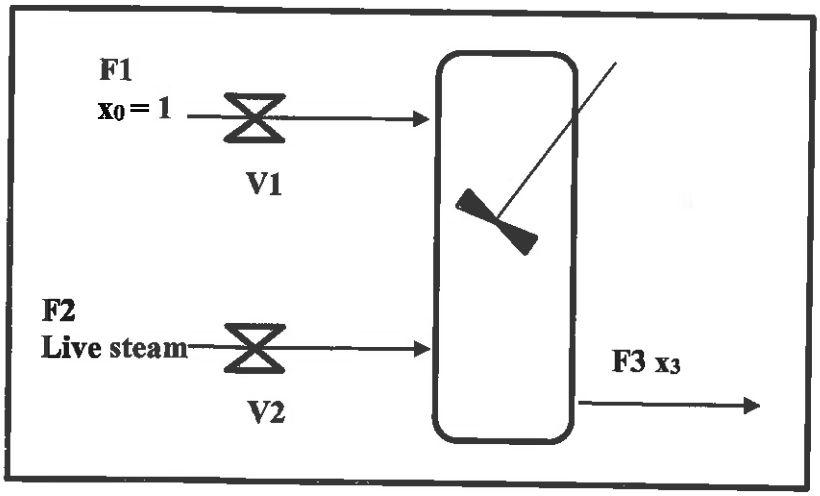


Figure 4. Stirred vessel controlling temperature and composition of stream F3.

Simple models of the system are assumed to be:

$$\frac{dT_3}{dt} = F_1 + 2F_2 - 2T_3$$

$$\frac{dx_3}{dt} = -F_1 - 2x_3$$

a) Re-write the above equations in single vector-matrix form (2)

b) If a proportional feedback controller with a gain of (5)

$$K_c = \begin{bmatrix} 1 & 3 \\ 2 & 3 \end{bmatrix}$$

is employed to regulate T_3 and x_3, determine if the system is closed-loop stable

c) What is the significance of the Morari Resiliency Index (MRI)? (3)

d) Find the steady-state relation between

$$\begin{pmatrix} T_3 \\ x_3 \end{pmatrix} \text{ and } \begin{pmatrix} F_1 \\ F_2 \end{pmatrix}$$

and use it to determine the MRI of the system. (7)

TOTAL /17/

QUESTION 4

The phthalic anhydride (PA) converter shown in Figure 5 on the attached sheet has V_2O_5 catalyst packed in tubes, with the tubes surrounded by a heat transfer salt (HTS) solution. The HTS is in turn cooled by generating steam in boiler coils passing through the shell-side of the converter. The PA in the stream leaving the reactor is condensed and pumped away, whilst the remaining non-condensables proceed to a catalytic combustor. Show the following controls on the accompanying diagram:

(a) O-xylene is on flow control

(1)

(b) Air flow rate is ratioed to the o-xylene flow rate.

(2)

(c) BFW valve is used to control the maximum of three temperatures measured in the catalytic tubes.

(2)

(d) Condenser temperature control is cascaded to a flow rate controller on the CW.

(2)

(e) Reaction pressure is controlled using the non-condensables valve.

(1)

(f) Accumulator level is controlled using the Raw PA valve

(1)

(g) A maximum temperature is allowed exit the reactor – if this is exceeded, the o-xylene valve is pinched shut

(2)

(h) A maximum level is allowed in the accumulator – if this is exceeded, the CW is pinched shut.

(2)

TOTAL /13/

DIAGRAM FOR QUESTION 4

DETACH THIS PAGE AND SUBMIT WITH ANSWER BOOKLET A

NAME: _____ **STUDENT NUMBER:** _____

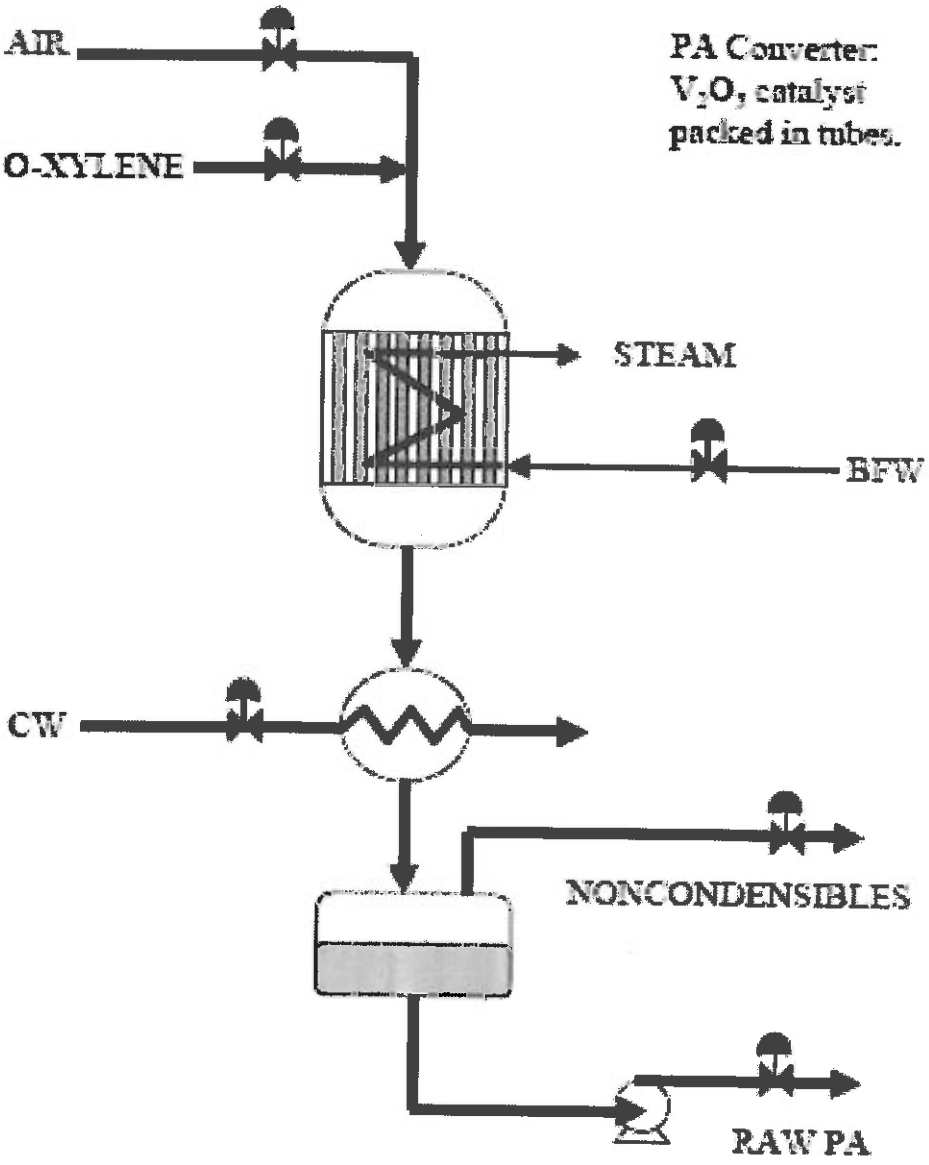


Figure 5. Phthalic anhydride (PA) converter

SECTION B

QUESTION 5

Consider a 2-stage separation (series) process, with each stage given by

$$G_{pi} = \frac{1}{(s + k_i)}$$

We have $k_1 = 3, k_2 = 2$. There is cooling between the stages with the following transfer function

$$G_{cooling} = \frac{1}{s + 2.5}$$

Other contributions are negligible.

a) What is the openloop transfer function?

(5)

b) Determine the ultimate gain for P and PI controllers with a value of 0.5 for the integral time constant.

(15)

Additional information:

Please note that when plotting root locus diagrams, the ffg relationships are useful.
Centre of gravity:

$$CG = \frac{\sum_i p_i - \sum_i z_i}{n - m}$$

Asymptote angles

$$\alpha = \frac{2k + 1}{n - m}\pi$$

TOTAL /20/

QUESTION 6

The Bode plot provided on page 9 has been constructed for a non-linear chemical process. The process is fairly stable, however, we wish to install a pre-heater before the reactor which is known to contribute the following dynamics:

$$G = s + 2$$

a) To what extent will the heat exchanger destabilise the process? Draw on the Bode plot and submit with your answer book.

(10)

b) If we install a proportional controller before the heat exchanger, what K_c value will guarantee a gain margin of -5dB?

(5)

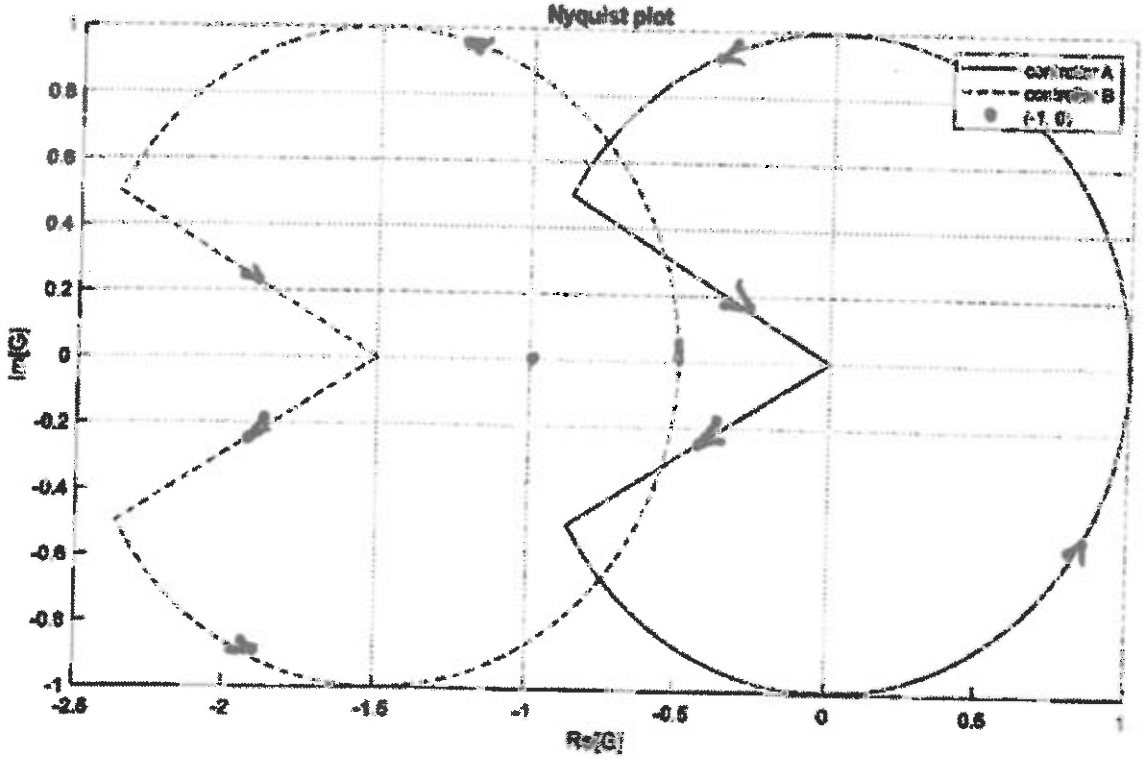
c) From a plot on the Nichols chart (provided on page 10), describe the effectiveness of a proportional controller to accomplish a closedloop resonant peak of 2dB.

(10)

TOTAL /25/

QUESTION 7

Consider two controllers, A and B. The openloop response to a given process for each of these controllers is shown in the Nyquist plot below.



Which controller yields stable operation? Explain your answer.

TOTAL /5/

DIAGRAM FOR QUESTION 6

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NAME: _____ **STUDENT NUMBER:** _____

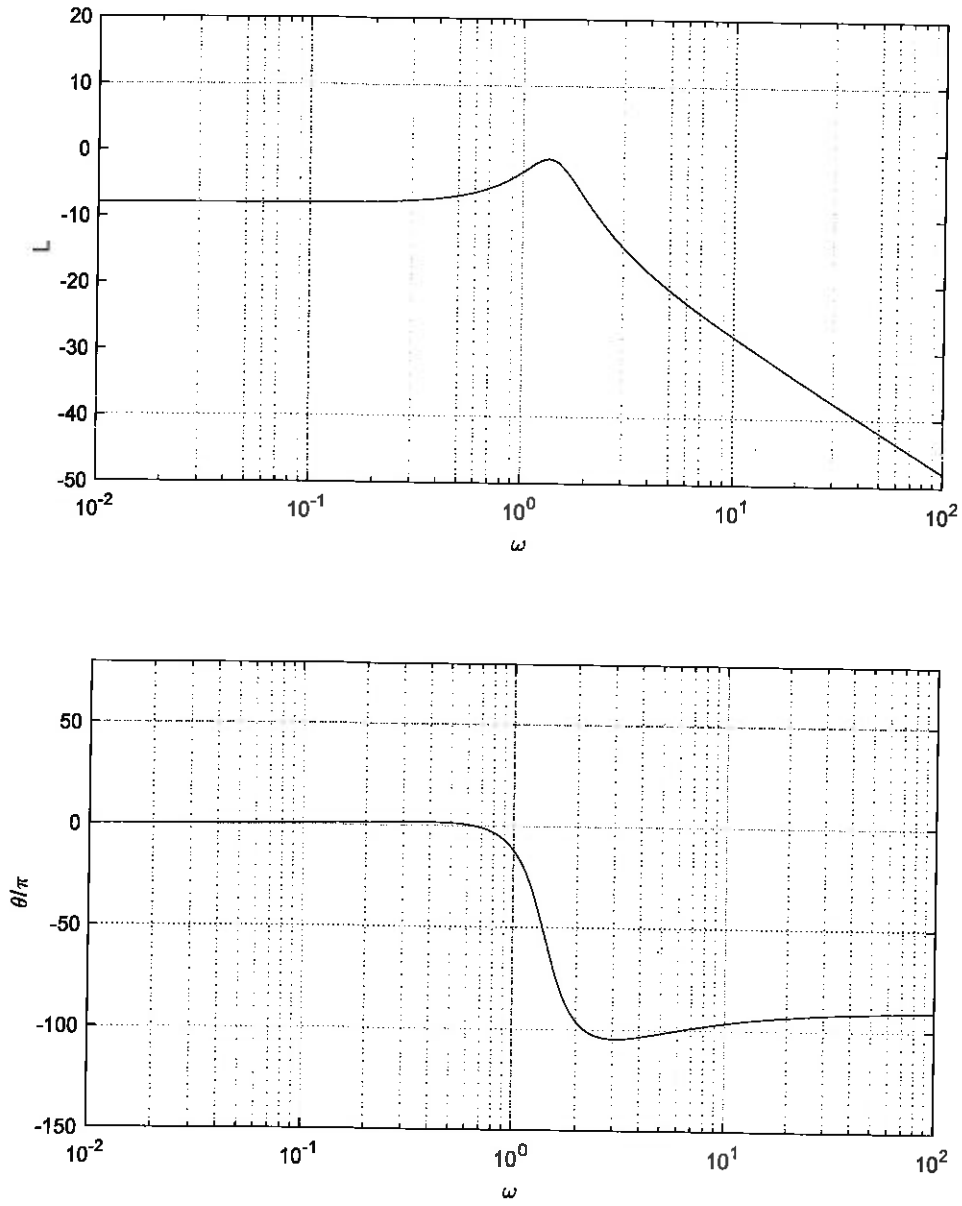

Figure 6. Bode plot has been constructed for a non-linear chemical process for Question 6

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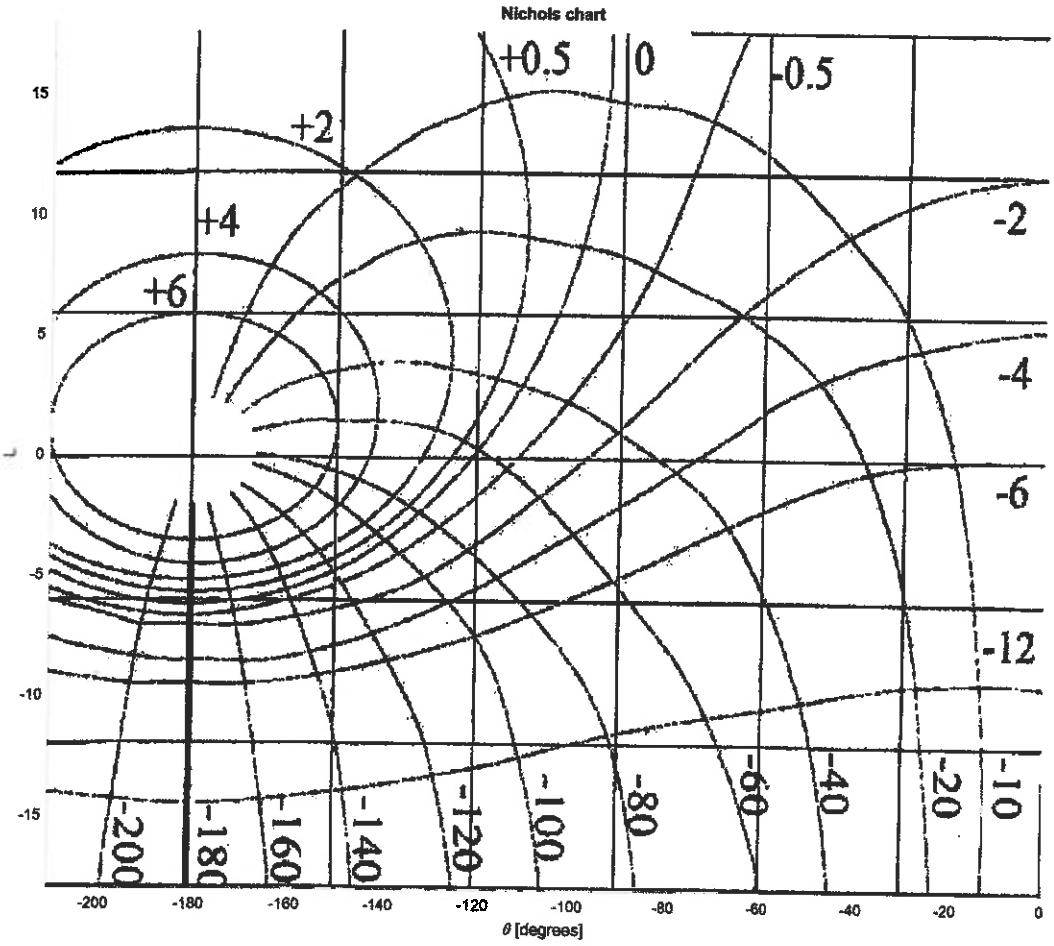

Figure 7. Nichols chart for Question 6