POLITECNICO
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OK

Automation of Energy Systems

(Modelling and Control of Energy Systems)

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Academic year 2020/2021
Exam call of 24 January 2022

Family name ______________________________

Given name(s) ______________________________

Reg. code ______________________________

Signature ______________________________

- This booklet contains a total of **12 pages**, including this cover and the last page with the phase ruler to detach. **Check that the booklet is complete** and if this is not the case signal the problem immediately.
- **Fill in the space above with your personal data and signature; do this now, and in ink**. For the rest of the exam you can use a pencil.
- Answer the questions in the spaces provided, **following the instructions precisely** and writing legibly; **order and clarity are part of the evaluation**.
- During the exam **you are not allowed to consult books, notes or any other material**.
- **Hand in only this booklet**: nothing else will be accepted.
- The sections of the exam report **indicative** scores, so as to give an idea of their relative weights. Keep in mind that these are just indications, of course reliable but **not to be taken as rigid constraints**. Scoring is done considering the exam as a whole.

Foreword — read carefully

If you are taking Automation of Energy Systems (hereinafter AES) as a standalone exam, you must answer all the questions in the booklet.

If you are taking this test as part of the Modelling and Control of Energy Systems (hereinafter MCES) exam, you must **NOT** answer the questions marked with **“AES only”**.

If taking MCES, do not answer “AES only” questions in an attempt to compensate for other possibly missing answers: **no marks will be awarded** for that.

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1 Multiple choice questions

This section is made of 30 questions for AES, 20 for MCES; only one of the proposed answers is correct. The total value of the section is **15 points**:

- each correct answer adds 0.5 points for AES, 0.75 for MCES,
- each incorrect answer subtracts 0.25 points for AES, 0.375 for MCES,
- answers not given have no effect.

Warning: answers must be provided by ticking the boxes on page 6, **not in the body of the questions**.

1 For ”renewable” energy we mean energy

a. automatically restored to its original repository.
b. from practically inexhaustible sources.
c. subject to contracts to be periodically re-negotiated.

2 In general, the utilisation of renewable energy

a. does not entail the release of pollutants.
b. is completely cost free.
c. requires no consumables except the energy source itself.

3 For “energy conservation” we mean

a. reducing energy consumption – or its growth – in absolute terms.
b. reducing energy cost.
c. storing energy in a safe place.

4 switching the generator on and off timely with respect to the power generation plan.

?

a. operating the generator as near as possible to its optimal efficiency condition, compatibly with the constraints in force.
b. switching the generator on and off timely with respect to the power generation plan.
c. coordinating the pool of generators that feed a particular set of utilisers.

5 The control quality achieved with a cascade control could not be obtained – in the same control problem – with a single-loop one

a. if there are relevant disturbances affecting the outer loop.
b. if there are relevant disturbances affecting the inner loop.
c. if the bandwidth separation between the two loops is not large enough.

6 In a 2×2 decoupler-controller structure, if antiwindup is applied upstream the decoupler and one of the physical control variables hits a saturation limit,

a. the affected loop slows down.
b. the effect is unpredictable, but for sure stability is preserved.
c. both loops can undergo highly undesired behaviour.

7 A Smith predictor will most likely not function correctly

a. if the delay is too large for the prediction block to react timely, as in that case rational dynamics prevails.
b. if there are significant unmeasured disturbances on the process to corrupt the used prediction.
c. if the process rational dynamics is not asymptotically stable, because the predictor block is in parallel to it.

8 The scheme in which several actuators are used in sequence, each one starting to act when the previous one has reached its limit, is called

a. split range.
b. cascaded.
c. daisy chain.

9 A major reason to employ daisy chain actuation is

a. having less "convenient" actuators intervene only when necessary.
b. allowing a controller to exert a signed action although actuators cannot.
c. alternating the actuators so as to distribute wear.

10 The two main control loops aboard a thermoelectric generator, from a system-centric viewpoint, concern

a. mechanical power and energy (pressure) level.
b. primary and secondary control.
c. primary and tertiary control (the secondary one is centralised). centralized too!

11 A relevant advantage of modern solar generators with tube captors is

a. the higher working temperatures.
b. the faster dynamics.
c. the possibility of introducing management-relevant storage.

12 In a hydroelectric generator the role of prime mover is played by ?

a. a water basin.
b. a hydraulic turbine.
c. a hydraulic turbine valve controller.

? which one

13 The power response of a thermoelectric generator to a throttling valve step

a. is practically instantaneous but then decays unless energy (pressure) is restored.
b. can be sustained indefinitely.
c. can be sustainable or net depending on the management policy.

14 The active and reactive generator-network power transfer are jointly governed by

a. machine angle and voltage amplitude.
b. machine angle and voltage phase.
c. power and frequency control.

15 A network admittance matrix is always

a. real. → we use admittance! Im Re values!
b. symmetric.
c. diagonalisable.

16 A major goal of energy management in thermal systems for residential installations is ?

a. to guarantee comfort with minimum expenditure.
b. to decide when heating or cooling is in order.
c. to keep strict temperature set points.

17 When confronted with multiple dynamic time scales, the most proper use of thermal energy is normally achieved by

a. focusing the control design on the slowest time scale, as this is the dominant dynamics.
b. considering all scales, for example by means of nested loops.
c. determining the time scale on which control needs centring based on the objective (e.g., comfort).

18 To help ambient condition control systems use less energy, set points are in general ?

a. kept constant whenever possible so as to minimise transients.
b. scheduled based on a periodic (e.g., daily) estimate/forecast of thermal loads.
c. adapted on line to avoid control saturation.

19 The main control loops in a heat network substation heat exchanger are

a. secondary and primary side outlet temperatures.
b. secondary side outlet temperature and primary side flowrate.
c. secondary side outlet temperature, possibly with primary side flow as inner cascade loop.

20 In a generic heat network, increasing the working fluid flowrate

a. reduces pumping consumption at the expense of heating consumption.
b. reduces heating consumption at the expense of pumping consumption.
c. has no influence on consumption.

21 **AES only.** In a cascade control structure having a temperature as the outer value, the inner one quite typically is

a. pressure.
b. flowrate.
c. level.

22 **AES only.** A major reason for possible realisability problems with feedforward compensation in thermal systems is the frequent presence of

a. high-order controllers.
b. process dynamics with high relative degree.
c. unstable dynamics.

23 **AES only.** In time division actuation, the base period

a. must be small with respect to the actuator dynamics so that the system is hardly affected by the switching.
b. needs not choosing with particular care.
c. must be small with respect to the process dynamics yet tolerable for cycling the actuator.

24 **AES only.** A generator can feed power to an AC grid through

a. a turbine.
b. an alternator or an inverter. OK
c. wires or pipes.

25 **AES only.** In an PI-controlled islanded generator case, a means to overcome or at least mitigate response speed imitations is

a. to increase the controller gain.
b. to increase the controller integral time.
c. to introduce derivative action.

26 **AES only.** In system-level models for thermoelectric generators, the control inputs are

a. power and frequency.
b. power and excitation voltage.
c. turbine throttling valve and combustion power.

27 **AES only.** Denoting by $\underline{y}_{ij}$ the line admittance between busses i and j, generic off-diagonal element of the admittance matrix for a network with n_B busses is

a. $\underline{Y}_{ii} = \underline{y}_{ii} + \sum_{j=1,j\neq i}^{n_B} \underline{y}_{ij}$
b. $\underline{Y}_{ij} = -\underline{y}_{ij}$
c. $\underline{Y}_{ij} = \underline{y}_{ij}$

28 **AES only.** A typical use of cascade controls in thermal energy systems is

a. to quench the difficulties posed by valve nonlinearities via inner flow loops.
b. to increase stability and robustness in general.
c. to allow a flow control loop to respond more promptly when required.

29 **AES only.** When operating two actuators with opposite action, a major advantage of a two-loop scheme over a split range one is

a. that setting two extremal set points governs the controlled variable swings better than a control dead zone.
b. that the two controllers are led to always use actuators up to a minimum.
c. that the tuning of the two controllers can be made equal.

30 **AES only.** The main disturbances relevant for loops in a heat network substation are

a. central heater power and flowrate variations.
b. local thermal load and flowrate/temperature variations from upstream.
c. hydraulic impedance variations from downstream.

Answers to the multiple choice questions

	a	b	c		a	b	c
1	▢	▢	▢	11	▢	▢	▢
2	▢	▢	▢	12	▢	▢	▢
3	▢	▢	▢	13	▢	▢	▢
4	▢	▢	▢	14	▢	▢	▢
5	▢	▢	▢	15	▢	▢	▢
6	▢	▢	▢	16	▢	▢	▢
7	▢	▢	▢	17	▢	▢	▢
8	▢	▢	▢	18	▢	▢	▢
9	▢	▢	▢	19	▢	▢	▢
10	▢	▢	▢	20	▢	▢	▢

AES only

	a	b	c
21	▢	▢	▢
22	▢	▢	▢
23	▢	▢	▢
24	▢	▢	▢
25	▢	▢	▢
26	▢	▢	▢
27	▢	▢	▢
28	▢	▢	▢
29	▢	▢	▢
30	▢	▢	▢

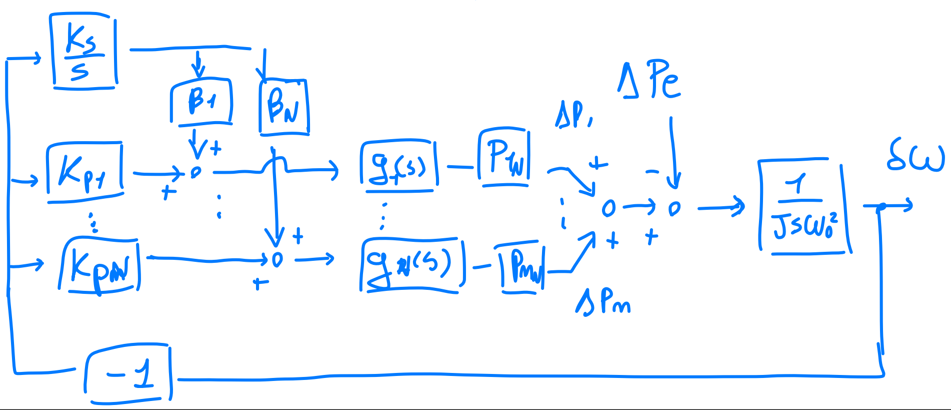
2 Open questions

The total **indicative** value of this section is **6 points**; partial values – indicative as well – are shown question by question.

Question 1 (AES 2 points, MCES 3 points)

Explain why in power/frequency control for an AC grid an integral action is required, why this needs to be centralised, and how the above is realised.

In an AC grid our goal is to control both Power and frequency, $\delta P = 0$ is guaranteed by the integrator of the open loop TF (given by the alternator T.F $1/sTA$) while to properly obtain a regime $\delta\omega = 0$, we need another integrator, so the controller should be a PI(D). Dealing with multiple generator "in parallel" we cannot place parallel integral action otherwise we lose controllability! so our control structure is composed by local P(D) plus centralized I action properly partitioned:



Question 2 (AES 2 points, MCES 3 points)

Illustrate how a price-taking energy utiliser can determine its optimum consumption level with a completely selfish approach.

In the utiliser P.O.V we can represent our problem considering a certain utility function $U(P_t)$ and a given cost Π_b [€/MWh] energy price

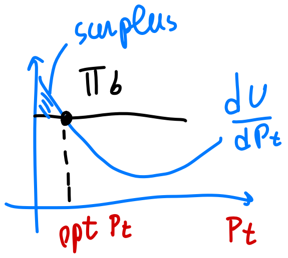
its objective is the maximization its utility rate as

$$\max_{P_t} \{ U(P_t) - \Pi_b P_t \} \rightarrow$$ so we can solve it as:

$$\frac{dU(P_t)}{dt} = \Pi_b$$ intersepting the constant Π_b with the derivative of utility !

which give us the optimum consumption level P_t

IF for example $U(P_t)$ is cubic



Question 3 (2 points) — AES only

List and briefly comment the major control problems emerging in heat networks.

dealing with control of heat network we have a variety of heterogeneus problems, requiring different tecniques

- Flow and pressure in liquides: deal with the transport of energy inside pipes controlling pressure to avoid overload, BUT with non linear dynamics due to valves, pipes and pump non linear relation.
- T control in pipes. manage the inlet of cold fluid or heat rate to control the T upstream a certain point
- Joint T/flow control: manage the control of a flowrate that has to mantain a certain Temp, to provide heat rate ... This become even complex on the decision of set points, and sometimes the better choice is to manage separately this control by a cascade scheme

3 Exercises

The total **indicative** value of this section is **12 points**; partial values – indicative as well – are shown exercise by exercise.

Exercise 1 (AES 5 points, MCES 12 points)

An AC grid at frequency $f_o = 50Hz$ contains two generators G1 and G2, both of nominal power $P = 50MW$ and characterised by a first-order dynamics with time constant $\tau = 10s$. The total inertia J is such that *with both generators active*, the equivalent time constant T_A is $20s$.

1. Draw a block diagram representing the above AC grid with power and frequency control in primary plus secondary form, assuming these to be respectively proportional and integral, and setting the secondary distribution coefficients to sum to the unity, that for G2 being three times that for G1.

2. Determine the primary and the secondary gains for a the closed-loop settling time of 3 minutes and a phase margin φ_m of 50° at least; report the obtained open-loop frequency response magnitude, as well as the computations related to response speed and stability degree, on the semilogarithmic sheet of page 9.

$P_{m1} = P_{m2} = 50MW$

$\tau_1 = \tau_2 = 10s$

1

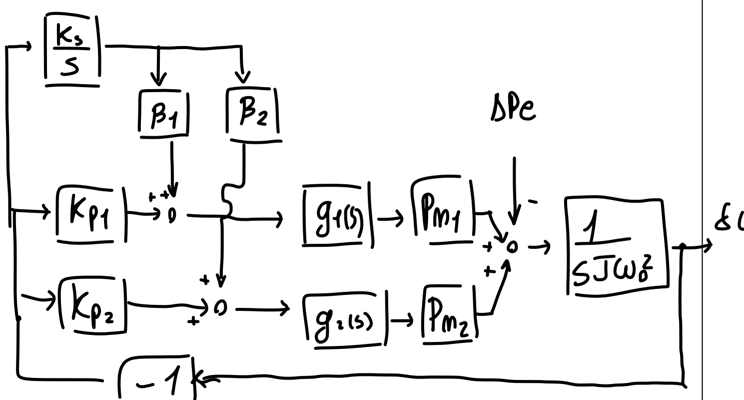
J t.c if G1, G2 ON → TA = 20s

$g_1(s) = g_2(s) = \dfrac{1}{1+10s}$

$f_0 = 50Hz \rightarrow \omega_0 = 2\pi f_0 = 314.16\ rad/s$

$\dfrac{P_{m1}+P_{m2}}{J\omega_0^2} = \dfrac{1}{T_A}$

$J_{TOT} = \dfrac{(P_{m1}+P_{m2})}{\omega_0^2} T_A = 20.26\ \dfrac{kJ}{(r/s)^2}$

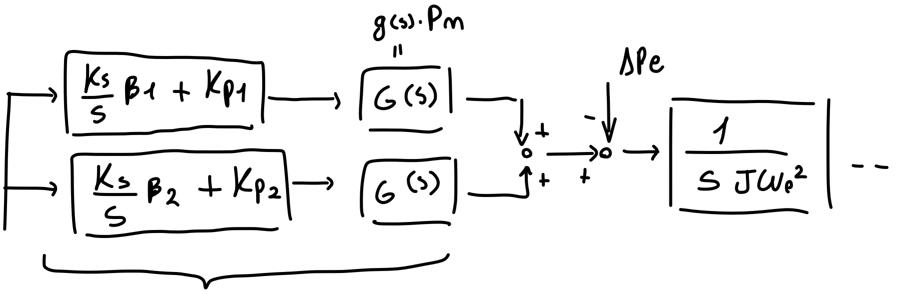


$\begin{cases} \beta_1 + \beta_2 = 1 \\ \beta_2 = 3\beta_1 \end{cases}$ $\begin{cases} \beta_1 + 3\beta_1 = 1 \Rightarrow \beta_1 = 1/4 \\ \beta_2 = 3/4 \end{cases}$

2 $t_{set} = 3min \rightarrow \omega_c = \dfrac{1}{\frac{3 \cdot 60}{5}} = 0.02\bar{7} \simeq 0.03$ (approx upside for robustness)

$\varphi_m \geq 50°$

first we have to bring the scheme to an easier formulation



$C(s) = K \dfrac{(1+100s)}{s}$

setting $K_{p1} = K_{p2} = K_p$ all become a controller $\left(\dfrac{K_s}{s} + 2K_p\right)$ acting on

$G(s) \cdot \dfrac{1}{sJ\omega_0^2}$ so we can tune it by loop shaping:

We loss 17° by the pole → to have $\varphi_m \geq 50°$ we need

$\varphi_z \geq 67°$ lett's say $\varphi_z \simeq 70° \rightarrow \dfrac{1}{T} = 0.01$

$\tilde{\omega} \simeq 0.02 \rightarrow (\tilde{\omega})^2 = \mu = 0.0004$ closed loop gain

$$K \cancel{\frac{1+sT}{s}} \frac{2P_m}{\cancel{1+s\tau}} \frac{1}{\cancel{s} J \omega_0^2 2} = 0.0004 \frac{\cancel{1+sT}}{\cancel{s^2}\, \cancel{(1+s\tau)}} \longrightarrow K = 0.0004 \frac{T_A}{2} = 0.004$$

so $$C(s) = 0.004 \frac{(1+100s)}{s} = \frac{K_s}{s} + 2K_p = K_s \frac{1+s(2K_p/K_s)}{s}$$

$$\begin{cases} K_s = 0.004 \\ \frac{2K_p}{K_s} = 100 \rightarrow K_p = 50K_s = 0.2 \end{cases}$$

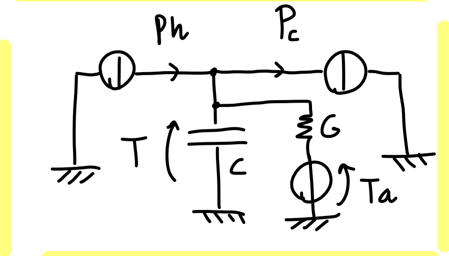
final tuning of primary / secondary

Exercise 2 (7 points) — AES only

Consider a thermal system in which a mass $M = 50kg$ of specific heat $c = 200J/kgK$ is connected to a heater with maximum power $P_{h,max} = 500W$ and a cooler with maximum power $P_{h,max} = 400W$ (*mind the signs to use throughout*). Both actuators have a first-order dynamics with time constant $\tau_h = 20s$. The mass disperses heat toward an exogenous ambient temperature T_a through a thermal conductance $G = 100W/K$.

1. Draw an electric equivalent for the system.
2. Draw and tune a control scheme with two PI controllers, one per actuator, to keep the temperature T of the mass between two values T_{lo} and T_{hi} acting on the heater and the cooler commands, both in the range $[0, 1]$, and aiming for a dominant closed-loop time constant in the range 40–50s for both the heating an the cooling case.
3. Should one decide to use a single controller plus a split-range block in the place of the above two-controller structure, would in your opinion the resulting scheme require complementing with actuator equalising filters and/or inner power loops? Why?

1 Writing the system dynamic $c\dot{T} = P_h - P_c - G(T - T_a)$ become easier to draw the equivalent: $\hookrightarrow C = Mc = 10000\ J/K$

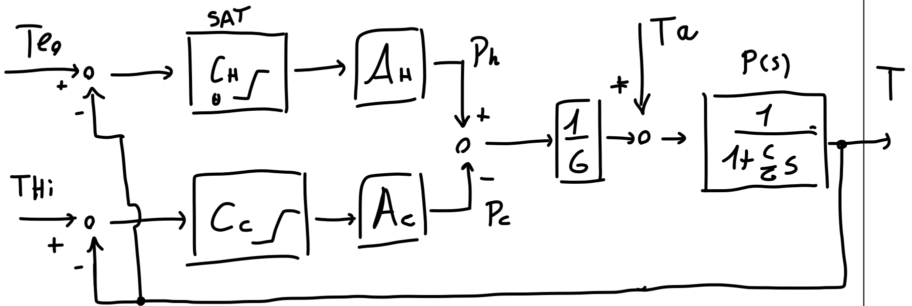


the system transfer function overall

$csT = P_h - P_c - GT + GT_a$

$$T = \frac{1}{G}\frac{P_h - P_c}{(1+\frac{c}{G}s)} + \frac{T_a}{(1+\frac{c}{G}s)}$$

2 the control scheme exploit SATURATION on the controllers to manage the control of T on a certain range



$\frac{1}{G} = 0.01$ $\quad P(s) = \frac{1}{1+\cancel{2}s} \rightarrow (1+100s)$

$$A_H = \frac{500}{1+20s} \qquad A_c = \frac{400}{1+20s}$$

to set up $\tau_c \simeq 40 \div 50s$, let's take $\omega_c \simeq \frac{1}{\tau_{c\,avg}} = 0.0\bar{2} \simeq 0.023$

and from here set the two controllers respect the seen dynamic requiring $L(s) = \frac{1}{45s}$

$$C_H A_H \frac{1}{G} P = \frac{1}{45s} \rightarrow C_H = \frac{1}{45s}\,\frac{\cancel{1+20s}}{500}\,(1+100s)\,0.01$$

$$C_H(s) = \frac{2\times10^{-5}}{45s}(1+100s)$$

we want a PI, so for realizability we remove the zero useless on $\frac{1}{20} > \frac{1}{45}$

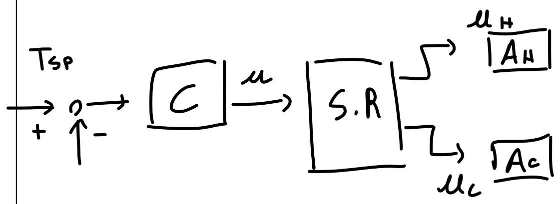
in the same way:

meg gain!

$\frac{1}{20} > \frac{1}{45}$

$$C_c(s) = -\frac{1}{45s}\,\frac{1+20s}{400}\,(1+\cancel{100}s)\,0.01 = \frac{2.5\times10^{-5}}{45s}\,\frac{1+200s}{400} \quad !!$$

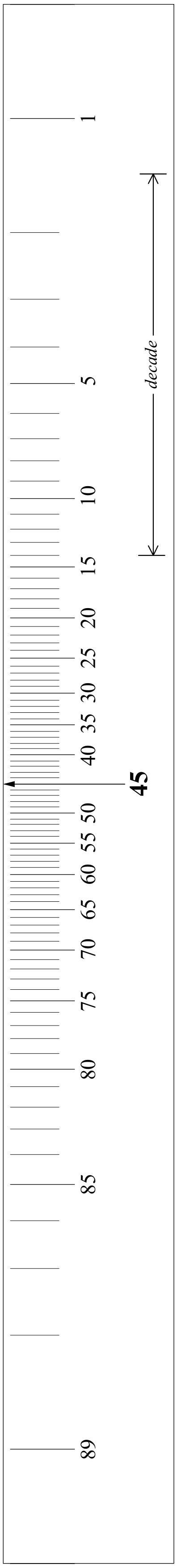
3 setting up another purpose scheme:
using a S.R with dead zones,



here A_H and A_C have the same time constant, so an equalising probably would not be necessary (that is needed when the controller sees different dynamic, causing tuning problems)

BUT even if equalization OR immer power loops is not needed, the relation between $T_{Hi/low}$ and the S.R dead zone is hard to evaluate!

? NOT SHURE!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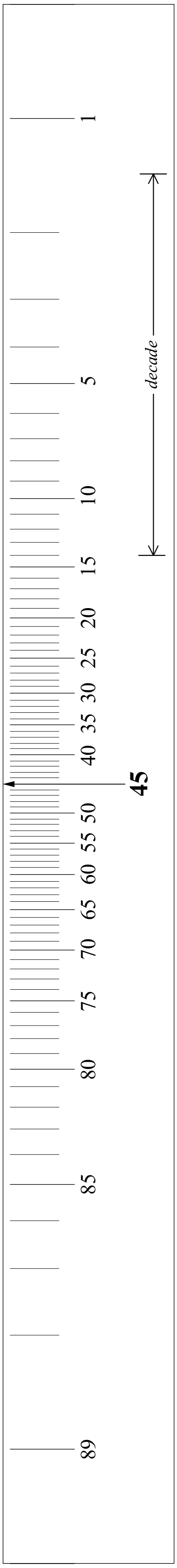
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